

INVESTIGATION INTO THE TOP FLANGE AND WEB DEFORMATION IN A CRANE GIRDER PANEL



Assignment report presented in partial fulfilment of the requirement for the
Degree of Master of Civil Engineering at the University of Stellenbosch

Study Leader: Prof. P.E. Dunaiski

December 2004

I, the undersigned, hereby declare that the work contained in this assignment was my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Signature:

Date:

SYNOPSIS

INVESTIGATION INTO THE TOP FLANGE AND WEB DEFORMATION OF A CRANE GIRDER PANEL

The purpose of this project was to study the deformations of the top flange and web of a girder panel resulting from loads, which have been imposed by an overhead travelling crane. This was achieved by designing a crane girder that represents dimensional ratios occurring in practice.

The first part of this project attempts to determine the properties of the crane girder. The crane girder was built from drawings in the workshop of the University of Stellenbosch's Civil-Department. Positions were identified where the strains were to be measured on the crane girder. The crane girder was subjected to loads according to SABS 0160 - 1989 and measurements were taken. The same beam was also modelled with finite elements. The numerical model was subjected to the same loads as the experimental crane girder.

Comparisons were then made between the results of the experimental investigation and those of the numerical model. Good comparisons were achieved between the results and the numerical model was assumed to be correct.

Other students could now use this model for investigating local stresses and strain effects that might cause fatigue and other in-service problems of electric overhead travelling cranes support structures in practice.

SAMEVATTING

ONDERSOEK NA DIE BOONSTE FLENSSE EN WEBVERVORMING VAN 'N KRAANBALKPANEEL

Die doel van hierdie projek was om die vervormings van die boonste flense en web van 'n kraanbalkpaneel te ondersoek, as gevolg van laste wat onderworpe was aan 'n oorhoofse kraanbalk. Dit was bereik deur 'n balk te ontwerp wat dimensionele verhoudings in die praktyk verteenwoordig.

In die eerste gedeelte van die projek word die eienskappe van die kraanbalk bepaal. Die kraanbalk was vanaf tekeninge in die werkswinkel van die Universiteit van Stellenbosch se Siviele Departement gebou. Posisies was geïdentifiseer waar die vervormings op die kraanbalk gemeet sou word. Die kraanbalk was onderwerp aan laste volgens SABS 0160 – 1989 en meetings was geneem. Dieselfde balk was ook gemodelleer met eindige elemente. Die numeriese model was aan dieselfde laste as die eksperimentele balk onderwerp.

Vergelykings was toe verkry tussen the resultate van die eksperimentele ondersoek en die numeriese model. Goeie vergelykings tussen die resultate was behaal en die numeriese model word as korrek aanvaar.

Ander studente kan nou hierdie model gebruik vir die ondersoek na lokale spannings en vervormingseffekte wat moontlik vermoeidheid en ander in-diens probleme van elastiese oorhoofse kraan ondersteunende strukture in the praktyk kan veroorsaak.

CONTENTS

LIST OF TABLES	IV
LIST OF FIGURES	V
LIST OF PHOTOS	VII
LIST OF SYMBOLS	VIII
 CHAPTER 1 - INTRODUCTION	 1-1
1.1 GENERAL	1-1
1.2 LOADS INDUCED BY OVERHEAD TRAVELLING CRANES	1-2
1.3 SCOPE OF RESEARCH PROJECT	1-3
 CHAPTER 2 - DESIGN OF CRANE GIRDERS	 2-1
2.1 GENERAL DESIGN APPROACH	2-1
2.1.1 DESIGN LOADS	2-2
2.1.1.1 Classification of the Crane	2-2
2.1.1.2 Vertical wheel loads	2-2
2.1.1.3 Transverse wheel loads	2-4
2.1.1.4 Longitudinal wheel loads and loads on end stops	2-5
2.1.2 TYPICAL DIMENSIONAL RATIOS	2-6
2.1.3 MATERIAL PROPERTIES	2-7
2.1.3.1 Crane Girder	2-7
2.1.3.2 Gantrex® MK6 Rail Pad	2-8
2.1.3.3 Rail	2-9
2.2 DESIGN	2-10
2.2.1 CRANE DATA	2-10
2.2.2 GENERAL ASSEMBLY	2-11
2.2.3 CRANE GIRDER PROPERTIES	2-12
2.2.3.1 Span of girder	2-12
2.2.3.2 Top flange	2-12
2.2.3.3 Bottom flange	2-12
2.2.3.4 Web	2-13
2.2.3.5 Intermediate and Bearing Stiffeners	2-13

2.2.3.6	Summary	2-14
2.2.4	RAIL PROPERTIES	2-15
2.3	CRANE GIRDER DESIGN	2-16
2.3.1	CALCULATION OF VERTICAL DEFLECTION	2-16
2.3.2	CALCULATION OF LATERAL HORIZONTAL DEFLECTION	2-18
2.3.3	CALCULATION OF STRESSES	2-19
2.4	SUMMARY OF THEORETICAL DESIGN RESULTS	2-20
CHAPTER 3 - EXPERIMENTAL INVESTIGATION		3-1
3.1	INTRODUCTION	3-1
3.2	TEST LOADS AND LOAD POSITIONS	3-3
3.3	TESTING APPARATUS	3-5
3.3.1	LOADING EQUIPMENT	3-7
3.3.1.1	Sway Frame	3-7
3.3.1.2	Load Application Equipment	3-8
3.3.2	MEASUREMENT INSTRUMENTATION	3-9
3.3.2.1	Amplifier	3-9
3.3.2.2	Load Cells	3-9
3.3.2.3	LVDT	3-9
3.3.2.4	Strain gauges	3-11
3.4	RESULTS OF EXPERIMENTAL INVESTIGATION	3-15
CHAPTER 4 - NUMERICAL MODEL		4-1
4.1	INTRODUCTION	4-1
4.2	TEST LOADS	4-2
4.3	MODEL DESCRIPTION	4-3
4.3.1	GENERAL	4-3
4.3.2	CRANE GIRDER	4-4
4.3.3	GANTREX PAD	4-5
4.3.4	RAIL	4-6
4.4	MODEL SIZE AND COMPUTATIONAL LIMITS	4-8
4.5	RESULTS OF NUMERICAL INVESTIGATION	4-9
CHAPTER 5 - VERIFICATION OF NUMERICAL MODEL		5-1
5.1	INTRODUCTION	5-1
5.2	COMPARISON OF RESULTS	5-2

CHAPTER 6 - EXTRACTION OF ADDITIONAL RESULTS FROM NUMERICAL MODEL	6-1
6.1 INTRODUCTION	6-1
6.2 ADDITIONAL ANALYSIS	6-2
6.3 ADDITIONAL RESULTS	6-2
 CHAPTER 7 - CONCLUSIONS	 7-1
 CHAPTER 8 - REFERENCES	 8-1
 CHAPTER 9 - ACKNOWLEDGEMENTS	 9-1
 APPENDIX A – TYPICAL DIMENSIONS OF CRANES AT SALDANHA STEEL	 A-1
 APPENDIX B – MATERIAL PROPERTIES OF STEEL USED FOR THE MANUFACTURING OF THE CRANE GIRDER	 B-1
 APPENDIX C – DESIGN FILE FOR THE CRANE GIRDER	 C-1
 APPENDIX D – DESIGN DRAWINGS FOR THE CONSTRUCTION OF THE EXPERIMENTAL CRANE GIRDER	 D-1

LIST OF TABLES

TABLE 2.1: TYPICAL DIMENSIONAL RATIOS FROM CRANE GIRDERS AT SALDANHA STEEL PLANT	2-6
TABLE 3.1: DEFLECTION MEASURED DURING EXPERIMENTAL INVESTIGATION	3-15
TABLE 4.1: CRANE GIRDER MODEL SIZE	4-4
TABLE 4.2: ELASTOMERIC PAD MODEL SIZE	4-5
TABLE 4.3: CRANE GIRDER MODEL SIZE	4-7
TABLE 4.4: DEFLECTION DETERMINED DURING NUMERICAL INVESTIGATION	4-9
TABLE 5.1: DEFLECTION COMPARISON	5-2
TABLE B1: TEST SPECIMEN SIZES (STEEL)	B-1

LIST OF FIGURES

FIGURE 2.1: PLAN OF CRANE INDICATING TRANSVERSE WHEEL LOAD DIRECTIONS	2-4
FIGURE 2.2: MATERIAL PROPERTIES OF CRANE GIRDER STEEL	2-7
FIGURE 2.3: STRESS STRAIN CURVE OF ELASTOMERIC PAD	2-8
FIGURE 2.4: GENERAL CRANE CRAB AND CRANE BRIDGE LAYOUT	2-10
FIGURE 2.5: GENERAL ASSEMBLY	2-11
FIGURE 2.6: GIRDER CROSS SECTION	2-14
FIGURE 2.7: RAIL SECTION	2-15
FIGURE 2.8: COMBINED SECTION USED FOR VERTICAL DEFLECTION	2-16
FIGURE 2.9: SECTION USED FOR LATERAL HORIZONTAL DEFLECTION	2-18
FIGURE 2.10: EXPECTED STRESS DISTRIBUTION OVER DEPTH OF GIRDER AT MIDSPAN	2-20
FIGURE 3.1: POSITION 1 – LAYOUT AND FORCE EFFECTS	3-3
FIGURE 3.2: POSITION 1 – LAYOUT AND FORCE EFFECTS	3-4
FIGURE 3.3: GENERAL ARRANGEMENT OF EXPERIMENTAL SETUP	3-5
FIGURE 3.4: SWAY FRAME WITH LOAD CELLS AND ACTUATORS INDICATING SETUP	3-7
FIGURE 3.5: CROSS SYSTEM SHOWING PATH OF LOAD ONTO RAIL	3-8
FIGURE 3.6: POSITIONS OF LVDTs ON TEST BEAM	3-10
FIGURE 3.7: POSITIONS OF STRAIN GAUGES	3-12
FIGURE 3.8: GENERAL STRAIN ROSETTE	3-13
FIGURE 3.9: VON MISES STRESSES OVER DEPTH OF BEAM AT MIDSPAN AS DETERMINED EXPERIMENTALLY	3-17
FIGURE 3.10: VON MISES STRESSES AT FLANGES OF BEAM AT MIDSPAN AS DETERMINED EXPERIMENTALLY	3-18
FIGURE 3.11: VON MISES STRESSES OVER DEPTH OF BEAM AT END PANEL	3-20
FIGURE 4.1: CRANE GIRDER MESH LAYOUT	4-4
FIGURE 4.2: GANTREX MK6 ELASTOMERIC RAIL PAD MESH LAYOUT	4-5
FIGURE 4.3: LAYOUT OF 30 kg/m RAIL	4-6
FIGURE 4.4: 30 kg/m RAIL MESH LAYOUT	4-7
FIGURE 4.5: VON MISES STRESSES OVER DEPTH OF BEAM AT MIDSPAN AS DETERMINED NUMERICALLY	4-11

FIGURE 4.6: VON MISES STRESSES AT FLANGES OF BEAM AT MIDSPAN AS DETERMINED NUMERICALLY	4-12
FIGURE 4.7: FEM RESULTS INDICATING VON MISES STRESSES DUE TO VERTICAL LOAD ONLY AS DETERMINED NUMERICALLY	4-13
FIGURE 4.8: FEM RESULTS INDICATING STRESSES IN DIRECTION 3 DUE TO VERTICAL AND HORIZONTAL LOADS (MISALIGNMENT) AS DETERMINED NUMERICALLY	4-14
FIGURE 4.9: FEM RESULTS INDICATING VON MISES STRESSES DUE TO VERTICAL- AND HORIZONTAL LOADS (MISALIGNMENT) AS DETERMINED NUMERICALLY	4-15
FIGURE 4.10: VON MISES STRESSES OVER DEPTH OF BEAM AT SUPPORT AS DETERMINED NUMERICALLY	4-17
FIGURE 5.1: VON MISES STRESSES-VERTICAL LOAD ONLY OVER DEPTH OF BEAM AT MIDSPAN	5-3
FIGURE 5.2: VON MISES STRESSES-VERTICAL AND MISALIGNMENT LOADS OVER DEPTH OF BEAM AT MIDSPAN	5-4
FIGURE 5.3: VON MISES STRESSES-VERTICAL LOADS ONLY AT FLANGES OF BEAM AT MIDSPAN	5-5
FIGURE 6.1: ADDITIONAL LOAD POSITIONS FOR ADDITIONAL RESEARCH	6-2
FIGURE B1: TEST PIECES – DRAWINGS ISSUED FOR CONSTRUCTION	B-3
FIGURE B2: STRESS STRAIN CURVE	B-4

LIST OF PHOTOS

PHOTO 3.1: EXPERIMENTAL SETUP	3-1
PHOTO 3.2: INSTALLATION PROCEDURES OF CLIPS	3-2
PHOTO 3.1: SHEAR ZONE IN END PANEL	3-19
PHOTO B1: TEST PIECES BEFORE TESTING	B-2

LIST OF SYMBOLS

λ	Factor
Δ_0	Displacement sideways of the bottom flange such as sweep
β	Warping torsion coefficient modifier
β_1	Factor
β_2	Factor
β_x	Factor
ω_2	Factor
Δ_{bot}	Displacement sideways of the bottom flange due to torsion and horizontal bending
Δ_{tilt}	Sum of Δ_0 , Δ_{top} and Δ_{bot}
Δ_{top}	Displacement sideways of the top flange due to vertical wheel loads, torsion and horizontal bending
Δ_x	Maximum deflection of a beam or girder
Δ_{xTest}	Test if maximum deflection were in bounds
Δ_{tTest}	Test if maximum deflection were in bounds
A	Area of cross section
a	Distance from left support to centre of two applied loads
A_v	Area of web stiffeners
b	Distance from right support to centre of two applied loads
b_{fb}	Width of bottom flange
b_{rail}	Width of rail
b_{ft}	Width of top flange
c	Distance from centre of gravity of two applied loads to applied load
C_{lass}	Class of section
C_{lassf}	Class of flange
C_{lassw}	Class of web
$C_{CombinedStresses}$	Combined strength test
$C_{omStBot}$	Compression strength of bottom flange test

$C_{omStTop}$	Compression strength op top flange test
C_w	Warping torsional constant
e	Eccentricity of load
E	Elasticity Modulus of steel (200GPa)
f_b	Stress due to bending
f_{bBot}	Total bending stress of bottom flange
f_{bTop}	Total bending stress of top flange
f_{bw}	Local wheel bending stress in the top flange of a crane girder
f_{cre}	Elastic critical plate-buckling stress in shear
F_{cri}	Inelastic critical plate-buckling stress in shear
f_{cri}	Local applied compression (bearing) stress of the top of the web
F_t	Force required to brace a column
f_{vu}	Ultimate shear strength
f_{xBot}	Yield strength of bottom flange
f_{xTop}	Yield strength of top flange
f_y	Yield strength (300MPa)
f_{yBot}	Total bending stress in the bottom flange due to bending as a result of lateral loads
f_{yTop}	Total bending stress in the top flange due to bending as a result of lateral loads
G	Shear modulus of steel
h_{rail}	Height of rail
h_{tot}	Distance from the centroid of the top flange to centroid of the bottom flange
h_w	Height of web
I_{rail}	Moment of inertia of rail
I_x	Moment of inertia of section over neutral x axis
I_{xbot}	Moment of inertia of bottom flange over neutral x axis
I_{xtop}	Moment of inertia of top flange over neutral x axis
I_{xweb}	Moment of inertia of web over neutral x axis
I_{xxTop}	Moment of inertia of top flange over top flange neutral axis

I_y	Moment of inertia of section over y axis
I_{yB}	Moment of inertia of bottom flange over y axis
I_{yT}	Moment of inertia of top flange over y axis
J	St. Venant's torsion constant
K	Effective length factor
k_v	Shear buckling coefficient
l	Span of beam (a+b)
M_{cr}	Critical elastic moment of laterally unbraced beam
M_p	Plastic moment = $Z_p f_y$
M_r	Factored moment resistance of member or component
M_{r12}	Factored moment resistance for class 1 and 2
M_{r34}	Factored moment resistance for class 3 and 4
M_{xx}	Moment, bending moment in member or component under serviceability load
M_y	Yield moment = $Z_e f_y$
M_{yBot}	Moment applied to the strong axis of the bottom flange of the crane girder
M_{yTop}	Moment applied to the strong axis of the top flange of the crane girder
M_{yy}	See M_{xx}
NA	Neutral axis of section measured from bottom
P	Concentrated externally applied load
ν	Poisson's ratio
α	Ratio of the span length to the applied torque
s	Centre to centre distance between transverse web stiffeners
$S_{stabilityWeb}$	Test for stability of web
T	Applied crane thrust
t_{fb}	Thickness of bottom flange
t_{ft}	Thickness of top flange
t_w	Thickness of web
V_r	Factored shear resistance of a member or component
V_{Test}	Test if resist to shear
V_{ui}	Ultimate shear

W	Nominal horizontal load
W_1	Equivalent thrust generated at top flange from applied force W
W_{10}	Factored W_6
W_2	Equivalent thrust generated at bottom flange from applied force W
W_3	Equivalent thrust generated at top and bottom flange from applied torsion, T
W_4	Equivalent thrust generated at top flange from applied force W . (W at y_o)
W_5	Equivalent thrust generated at bottom flange from applied force W . (W at y_o)
W_6	Equivalent thrust generated at top and bottom flange from applied load P if applied with eccentricity e
W_7	Same as W_4
W_8	Same as W_5
W_9	Factored W_3
W_{ebCrip}	Web crippling test
y_o	Distance from the bottom of girder to shear centre of girder
Z_e	Elastic section modulus of steel section
Z_{pl}	Plastic section modulus of steel section

CHAPTER 1 - INTRODUCTION

1.1 GENERAL

This Project was a Subproject of Project 1 – Electric overhead travelling (EOT) Cranes Support Structure Investigation. The purpose of Project 1 – EOT Cranes Support Structure Investigation, was to determine the in-service problems experienced with EOT Cranes. Examples of these problems are:

- Fatigue cracking of the flange-to-web weld
- Fatigue cracking local to the top ends of the welds connecting the stiffeners to the web
- Cracking of the welds at the top of the bearing stiffeners, at the columns, where they were connected to the top flange

The purpose of this study was to establish and verify a finite element model for current and future research.

1.2 LOADS INDUCED BY OVERHEAD TRAVELLING CRANES

According to SABS 0160-1989^[1], the following loads were generally applied to the overhead travelling crane rail:

- 1 Vertical loading: Crab weight, bridge weight and hoisted load.
- 2 Transverse loading: Crab surge or braking, misalignment of crane wheels or gantry rails, and skewing of the crane.
- 3 Torsional loading: The forces acting transversely, at the railhead, produce a torsional moment in the flange web region, which may be aggravated by the eccentric application of the vertical load referred to earlier.

^[1] SABS 0160 – 1989, South African Bureau of Standards, Private bag X191, Pretoria.

1.3 SCOPE OF RESEARCH PROJECT

This study required the application of analytical theory and numerical techniques, i.e. theory of mechanics and finite element method and experimental verification in order to determine the following:

- 1 Web deformations and forces (strains and stresses) developing in a crane girder due to concentrated vertical and horizontal crane wheel loads
- 2 Top-flange deformation and forces (strains, stresses and rotation) in a crane girder panel due to concentrated vertical loads and torsional loading
- 3 The determination of the deformations and forces in (1) and (2) with analytical numeric model, i.e. finite element method
- 4 Verification of the analytical and numerical models and results by comparison with experimental results obtained in the laboratory. For the comparison of the different models, the following had to be taken into account:

Deflection	Elastic Deflection
Stresses	Von Mises Stresses

CHAPTER 2 - DESIGN OF CRANE GIRDERS

2.1 GENERAL DESIGN APPROACH

A girder that could be tested in the laboratory of the University of Stellenbosch, together with the use of elements of previous tests (i.e. Gantrex® pad and Rail) had to be designed. With these constraints in mind, a crane girder was sized and designed.

Constraints:

The limitations of the laboratory of the University of Stellenbosch Civil Engineering Department and the availability of material placed restraints on the design. These included the following:

Rail Size: The rail size used in other studies conducted at the University at the stage of testing was 30 kg/m. It was decided that the same rail size had to be used since the material was available. The rail size has a direct influence on the top flange width.

Design Loads: The maximum load that could be measured was 20 tonnes, since load cells with a capacity exceeding 20 tonnes were not available. The design loads will be discussed in more detail under Design Loads in Chapter 2.1.1.

Maximum Span: The test support structure could support a beam with a maximum span of 11.0 meters. It could have been possible to have a crane girder exceeding this length, but not without designing a bigger support structure.

Wheel Size: A crane wheel with a diameter of 265 mm was available. It was decided that the same wheel should be used. See chapter on experimental setup.

Type of Rail Pad and Clips: As for rail size, type and size of pad, as well as clips, it was decided to use those that were available. The type of rail pad used was the Gantrex ® MK6 Rail Pad, while the clips used were of the Stelcam ® 13 Bolttable Clip type.

Typical Dimensional Ratios: A crane girder that could represent crane girders used in practice, had to be designed. Typical dimensional ratios (depth to thickness of web, top flange to bottom flange, etc.) were gained from an investigation into crane girders in practice in South Africa. These dimensional ratios were presented in Appendix A.

Material Properties: The steel used in South Africa was normally mild steel with yield stress of 300 MPa. Testing of the materials was done on a Material Testing Machine. The material properties were summarised in Chapter 2.1.3 – Material Properties.

Alex Perez-Winkler^[2] also conducted testing on the pad material and clips during previous studies.

2.1.1 DESIGN LOADS

SABS 0160-1989^[1] was used to determine the design loads that would be used in both the experimental and numerical models. Paragraph 5.7 – Loads due to Overhead Cranes takes the designer through the following design steps:

2.1.1.1 Classification of the Crane

The classification of the crane was done in accordance with SABS 0160-1989^[1] Paragraph 5.7.2 – Classification of EOTCs. The different classes were numbered from 1 to 4, where 1 has the lowest service classification to 4 having the highest service classification. It was decided, for the purpose of this research, that a crane with a classification of 4 should be used. This resulted in higher transverse loads.

2.1.1.2 Vertical wheel loads

For the determination of the test loads reference to SABS 0160-1989^[1] Paragraph 5.7.3 – Vertical Loads were made. This paragraph in SABS indicates that the owner must specify the vertical wheel load. In the absence of an owner, it was decided to use

^[1] SABS 0160 – 1989, South African Bureau of Standards, Private Bag X191, Pretoria.

^[2] An Investigation of Overhead Crane Wheel/Rail/Girder Interaction, A.R. Perez Winkler, 2003.

SASCH^[3] to determine the allowable crane wheel forces to be used as the test loads. SASCH uses Crane Class, rail size and wheel diameter to determine the maximum load for each wheel. With all of the above parameters fixed (from previous studies), the maximum wheel load was calculated.

Also, according to SABS 0160-1989^[2]; Paragraph 5.7.3 – Vertical Loads, the impact factor for Class 4 cranes was equal to 1.3.

This can be shown as follows:

$$W = CdI_f$$

where

W = Vertical wheel load

C = 0.29 (for class 4 crane with rail size of 30 kg/m)

D = 265 mm

I_f = 1.3

thus

W = 100 kN

^[3] SASCH, South African Steel Construction Handbook, Third Edition, 1997.

2.1.1.3 Transverse wheel loads

According to SABS 0160-1989^[2], paragraph 5.7.4 – Horizontal Transverse Loads, these loads can be classified as misalignment and skewing.

For a Class 4 crane, the load scale factor for misalignment of the crane wheels of the rail and for skewing of the crane was 0.20. The direction these loads were imposed in can be seen in Figure 2-1: Plan of crane showing direction of transverse wheel loads.

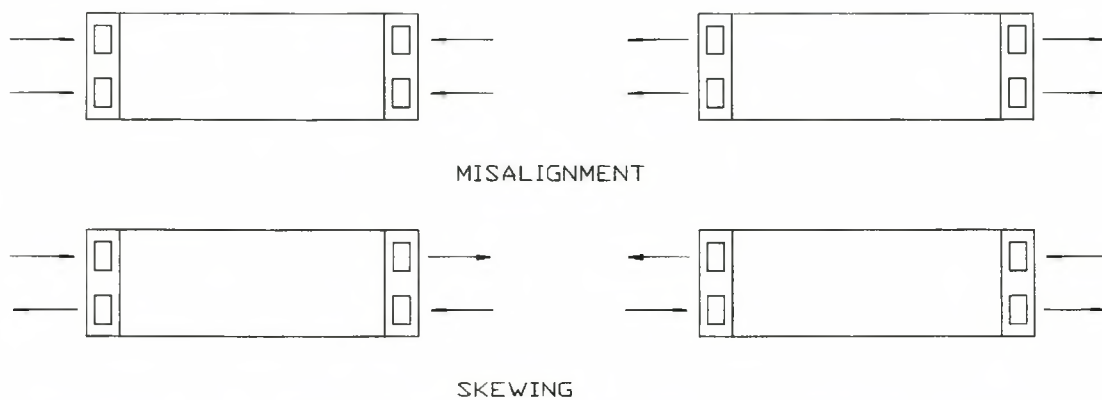


FIGURE 2.1: PLAN OF CRANE INDICATING TRANSVERSE WHEEL LOAD DIRECTIONS

This can be shown as follows:

$$P = WX_i$$

where:

P = Transverse wheel load

W = Vertical wheel load

$X_i = 0.2$ (Scale factor for misalignment and skewing)

Thus

$$P = 20 \text{ kN}$$

2.1.1.4 Longitudinal wheel loads and loads on end stops

According to SABS 0160-1989^[2], paragraph 5.7.5 – Horizontal longitudinal loads, the load scale factor for the acceleration and braking of the crane was equal to 0.1. According to SABS 0160-1989^[2], paragraph 5.7.6 – Loads on end-stop, the load that must be used for the design were the smallest of (a) load equal to the weight of the crane bridge and the crab, and (b) the load when the crane travels at the maximum speed into the end-stop, taking the characteristics of the buffer and end stop into account.

2.1.2 TYPICAL DIMENSIONAL RATIOS

Typical EOT crane girder dimensions from the Saldanha steel plant were used for the preliminary sizing of the experimental crane girder. Since this plant has more than forty EOT cranes, a good correlation between the typical relationships of the following could be drawn.

- i – Height of web to thickness of web
- ii – Top flange width to thickness of top flange
- iii – Bottom flange width to thickness of bottom flange
- iv – Span to spacing of web stiffeners
- v – Span to height of web

Plans from the Saldanha steel plant were studied and the following information was recorded. See Appendix A for the complete table. As can be seen in the table in Appendix A, cranes with surge plates were also included in the calculation of these ratios. The averages were affected in a minor way than when the surge plates were not used in the calculation of the averages. This is due to the small number of cranes with surge plates in the sample investigated.

	Min	Max	Average
h_w/t_w	89.0	184.2	148.2
b_{ft}/t_{ft}	12.5	22.0	17.9
b_{fb}/t_{fb}	12.5	35.7	21.8
Span/s	7.8	24.0	13.7
s/h_w	0.5	1.3	0.8
Span/h	5.9	31.6	10.3

TABLE 2.1: TYPICAL DIMENSIONAL RATIOS FROM CRANE GIRDERS AT
SALDANHA STEEL PLANT

These ratios were used to determine the preliminary crane girder dimensions. As can be seen in Appendix C, not only these dimensional ratios were used in the calculation of the final element sizes.

2.1.3 MATERIAL PROPERTIES

2.1.3.1 Crane Girder

The steel used in the manufacturing of the crane girder was tested with the material testing machine at the University of Stellenbosch, and the results were shown in the figure below. The same properties were used in the numerical model. See Chapter 4 – *Numerical Model*. Only the elastic properties were identified, since all the girder tests had to take place in the elastic zone of the steel.

Stress - Strain Curves for Material Used in Crane Girder

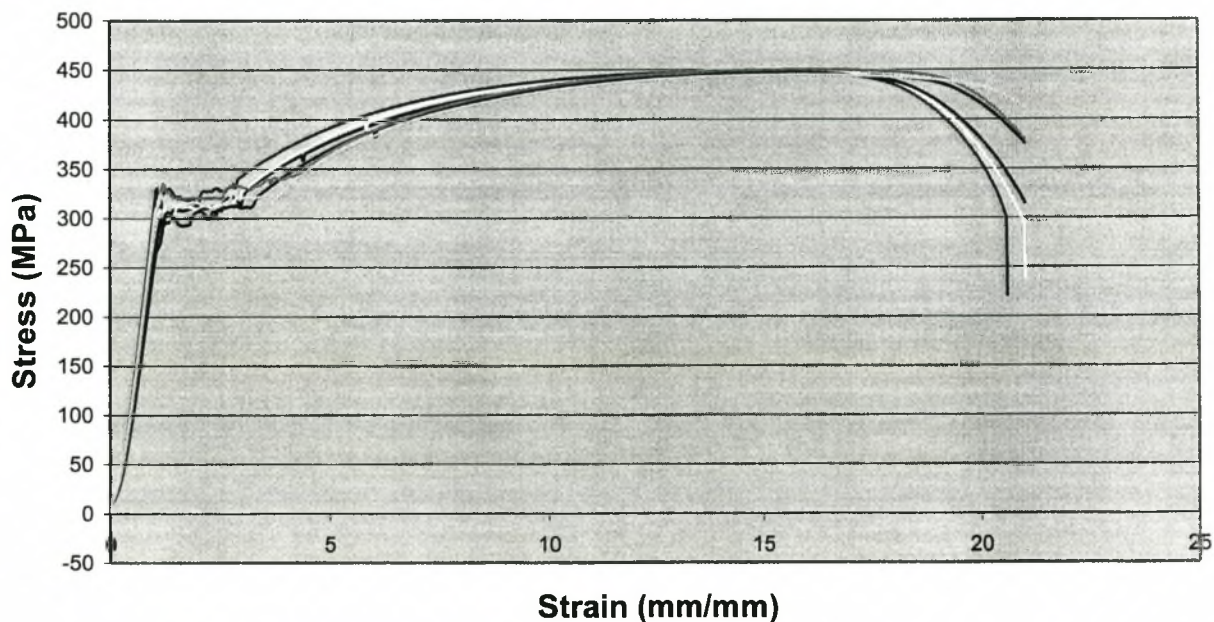


FIGURE 2.2: MATERIAL PROPERTIES OF CRANE GIRDER STEEL

Elastic:

Modules of Elasticity	203.5 GPa
Poison ratio:	0.3 (This ratio was not determined, but was used in the numerical model.)
Yield Stress	310.5 MPa

The test procedures for determining the material properties were given in Appendix B.

2.1.3.2 Gantrex® MK6 Rail Pad

The material properties were identified in the Structural Laboratory, Department of Civil Engineering, during a previous study, as was explained in Chapter 2.1.1 – *Restraints*. The pad was the only item expected to reach non-linear elastic state. It was thus decided to include the plastic properties of the Gantrex® pad. The properties that were used were as follows:

Elastic:

Modulus of Elasticity: 20 MPa
Poisson ratio: 0 (This ratio was not determined, but was used in the numerical model. A more accurate value would have been 0.5. This would only complicate the model, and no more accurate results (in the region of inspection) was expected.)

Plastic:

	Stress (MPa)	Deformation (mm/mm)
0	0	0
1	0.8	0.04
2	2.1	0.09
3	22.8	0.39

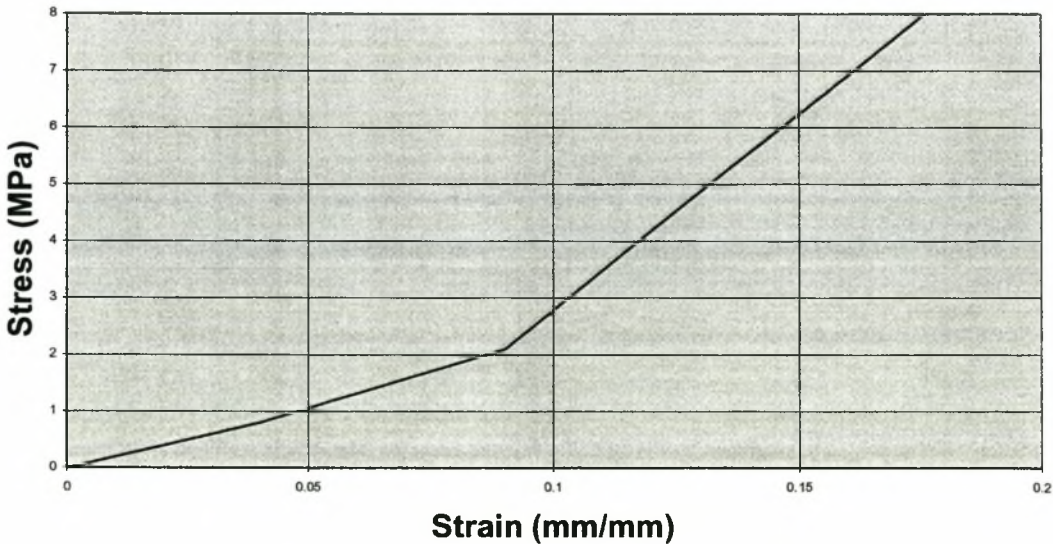


FIGURE 2.3: STRESS STRAIN CURVE OF ELASTOMERIC PAD

2.1.3.3 Rail

Material properties relating to the rail were also determined by Alex Perez-Winkler, and were as follows:

Elastic:

Modules of elasticity: 200 GPa

Poisson ratio: 0.3 (This ratio was not determined, but was used in the numerical model.)

Yield Stress: 360 MPa

2.2 DESIGN

With the dimensional ratios as discussed in the previous section, and with other criteria, for example classification, a preliminary crane girder was designed. The complete design was shown in Appendix C.

2.2.1 CRANE DATA

The basic crane data was discussed in this section.

The number of wheels: Four wheels, two wheels on each side, were used, as shown in Figure 2.4 *General crane crab and crane bridge layout*.

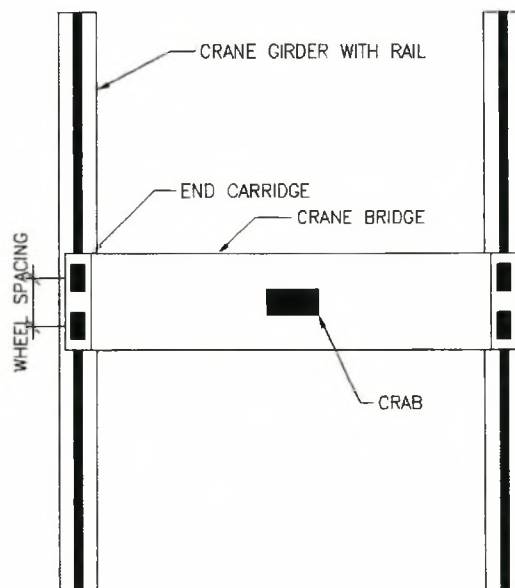


FIGURE 2.4: GENERAL CRANE CRAB AND CRANE BRIDGE LAYOUT

Class of Crane: A Class 4 Crane was used. See Chapter 2.1.1 Design Loads.

Rail size: A 30-kg/m rail was used. See Chapter 2.1. General Design Approach.

Wheel diameter: A 265 mm diameter wheel was used. See Chapter 2.1. General Design Approach.

Wheel spacing: A wheel spacing of 900 mm was used. See Chapter 2.2.2. General Assembly

2.2.2 GENERAL ASSEMBLY

The rail was connected to the top flange of the crane girder through rail clips. A bearing pad (Gantrex ® MK6) was installed between the rail and crane girder. The purpose of the pad was to:

- Distribute the wheel load over a large surface area;
- Eliminate load concentrations and the resulting fatigue stresses;
- Compensate for the uneven surface between the rail and its support;
- Reduce impact, vibration and noise;
- Eliminate fretting corrosion (wear) of the support surface under the rail.

The clips used were Stelcam ® 13 Boltable Clips and the purpose of the rail clips was to,

- Connect and align the rail to the crane girder;
- Give resistance to lateral force.

The clips were spaced according to the clip supplier, at 720 mm for the internal clips and 620 mm for the end clips. The required torque to the bolts connecting the clips to the top flange of the girder was also according to the supplier's specifications and was equal to 280 N.m.

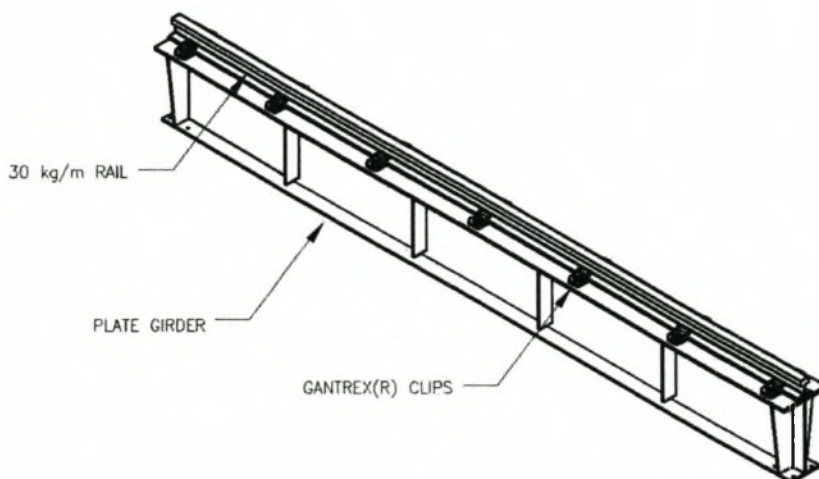


FIGURE 2.5: GENERAL ASSEMBLY

2.2.3 CRANE GIRDER PROPERTIES

The following section gives a summary of the general layout and sizes of members. The calculation of the crane girder sectional properties was shown in Appendix C.

2.2.3.1 Span of girder

The length of the girder was fixed at 4.5 m (4500 mm). This length was less than the maximum allowable length of the test structure of the support system.

2.2.3.2 Top flange

The width of the top flange (b_{ft}) was 300 mm. The following criteria was used in calculating the width of the top flange of the plate girder:

- Minimum width for the 30 kg/m rail and Stelcam ® 13 bolttable clips.

The thickness of the top flange (t_{ft}) was 20 mm. The thickness was calculated using the following criteria:

- Dimensional ratios (see Chapter 2.1.2 Typical dimensional ratios).
- Flange classification criteria (class 3 flange was used).
- Serviceability criteria (limits to horizontal deflection caused by misalignment using the top flange and rail only for resistance).

2.2.3.3 Bottom flange

The width of the bottom flange (b_{fb}) was 200 mm. The following criteria were used in calculating the width of the bottom flange.

- The minimum support width of crane column had to be greater or equal to half the top flange width.
- The correct second moment of the area of the bottom flange, as determined by the maximum vertical moment, to satisfy the required second moment of the girder had to be used.

The thickness of the bottom flange (t_b) was 10 mm. The thickness was calculated using the following criteria:

- Dimensional ratios (see Chapter 2.1.2 Typical dimensional ratios).
- Flange classification criteria (Class 3 flange was used).

2.2.3.4 Web

The depth of the web (h_w) was calculated to be 450 mm. The following criteria was used in calculating the depth of the web.

- Vertical deflection limit.

The thickness of the web (t_w) was 10 mm. The following criteria were used in calculating the thickness of the web.

- Dimensional ratios (see Chapter 2.1.2 Typical dimensional ratios).
- Slenderness limit (web classification)

2.2.3.5 Intermediate and Bearing Stiffeners

The thickness of the intermediate and bearing stiffeners was 10 mm. SABS 0162 – 1: 1993^[4], par 13.4.11 was used to calculate sizes and spacing of the intermediate stiffeners. The spacing of the stiffeners was 900 mm internally and 815 mm for the end stiffeners.

^[4] SABS 0162 – 1: 1993, South African Bureau of Standards, Private Bag X191, Pretoria.

2.2.3.6 Summary

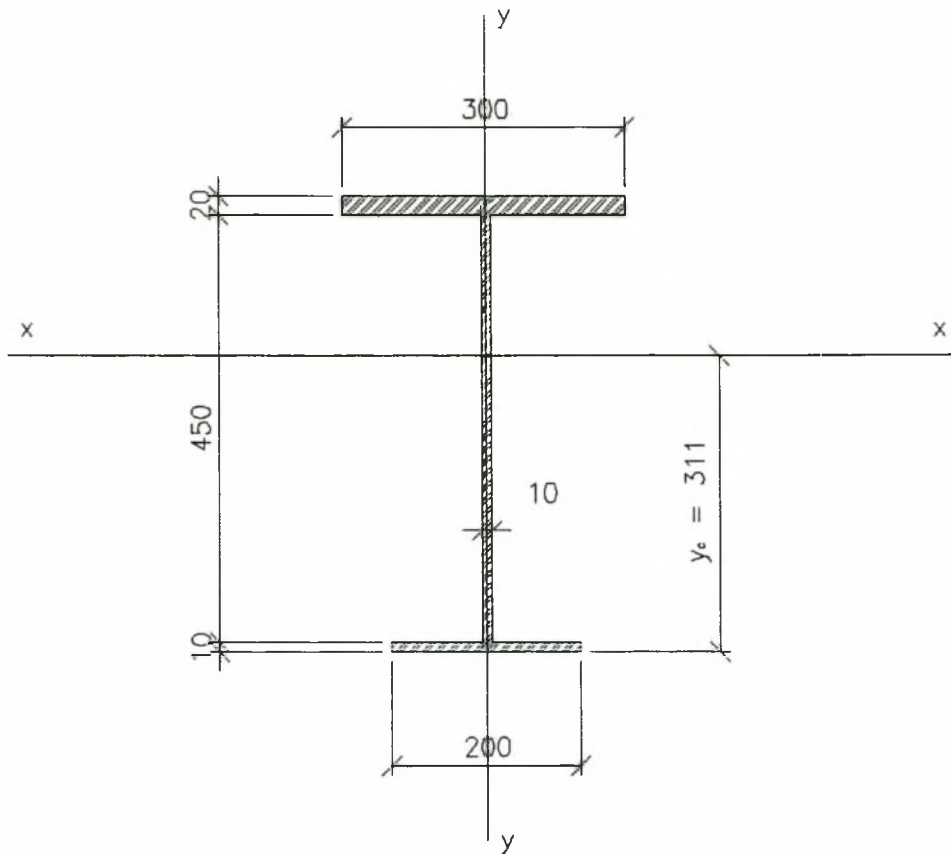


FIGURE 2.6: GIRDER CROSS SECTION

Section properties:

A	$=$	$12,50 \times 10^6$	mm^2
y_c	$=$	$311,00$	mm
$I_{\text{Girder},xx}$	$=$	$1650,00 \times 10^6$	mm^4
$I_{\text{Girder},yy, \text{ Top Flange}}$	$=$	$45,00 \times 10^6$	mm^4

Complete design drawings were presented in Appendix D.

2.2.4 RAIL PROPERTIES

As discussed in Chapter 2.1 *General design approach*, a 30 kg/m rail was used. The sectional properties of the 30 kg/m rail were shown in Figure 2.7: *Rail section*.

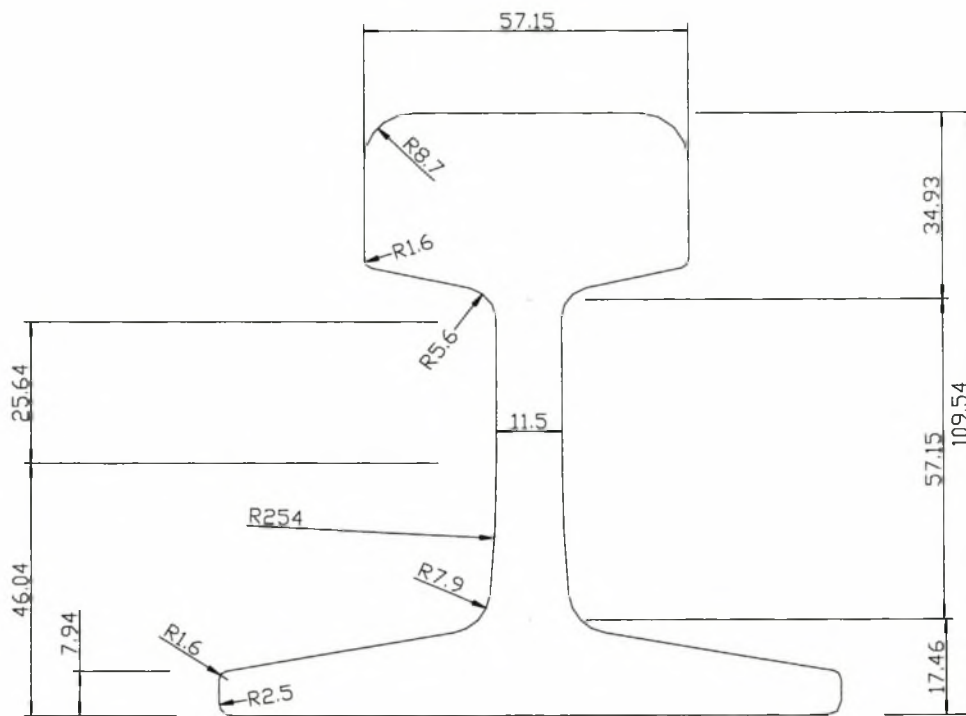


FIGURE 2.7: RAIL SECTION

Section properties:

A	$=$	$3,85 \times 10^6$	mm^2
y_c	$=$	$53,13$	mm
$I_{\text{Rail,xx}}$	$=$	$6,27 \times 10^6$	mm^4
$I_{\text{Rail,yy}}$	$=$	$1,57 \times 10^6$	mm^4

2.3 CRANE GIRDER DESIGN

2.3.1 CALCULATION OF VERTICAL DEFLECTION

No slip between the rail and the test girder was expected to take place at the test loads.

The moment of inertia of the combined section:

$$I_c = \left(I_{Girder,xx} + A_{Girder} \times \bar{y}^2 \right) + \left(I_{Rail,xx} + A_{Rail} \times \bar{y}^2 \right)$$

where:

$I_{Girder,xx}$	= Moment of inertia of crane girder
A_{Girder}	= Area of girder
$I_{Rail,xx}$	= Moment of inertia of rail
A_{Rail}	= Area of rail
\bar{y}	= 363,3 mm (Centroid of combined section)

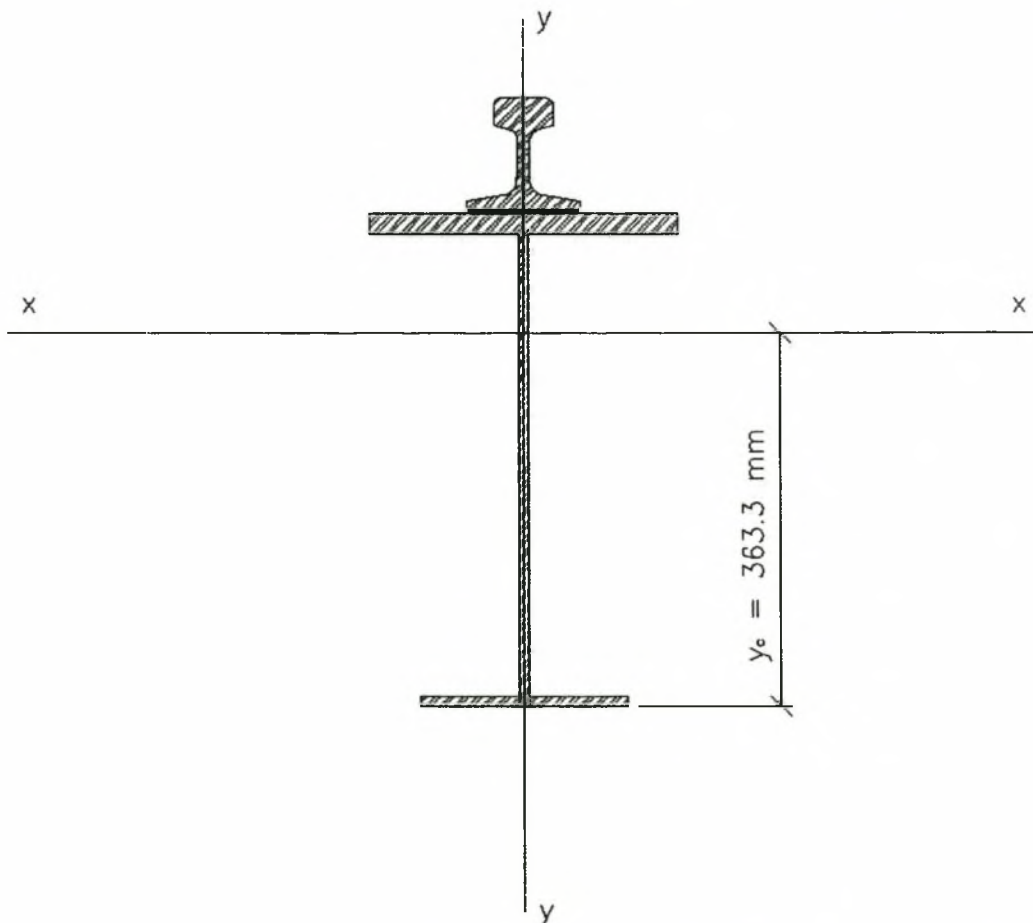


FIGURE 2.8: COMBINED SECTION USED FOR VERTICAL DEFLECTION

The moment of inertia of the “slipped” section:

$$I_{Slip} = (I_{Girder,xx}) + (I_{Rail,xx})$$

where: $I_{Girder,xx}$ = Moment of inertia of crane girder
 $I_{Rail,xx}$ = Moment of inertia of rail

The expected deflection will hence be:

$$\frac{Pl^2a}{24EI_c}(3 - 4\alpha^2) \leq \Delta \leq \frac{Pl^2a}{24EI_{Slip}}(3 - 4\alpha^2)$$

where: P = 100 kN
 a = 1800 mm (Distance from support to applied load)
 l = 4500 mm (Span)
 E = 203.5 GPa (Modules of Elasticity)
 I_c = $592.6 \times 10^6 \text{ mm}^4$ (Moment of Inertia of the combined section)
 I_{Slip} = $447.3 \times 10^6 \text{ mm}^4$ (Moment of Inertia of the “slipped” section)
 α = a/l

$$\underline{2.97 \leq \Delta \leq 3.94 \text{ mm}}$$

This range was used for the calculation of the deflection meter instrumentation in the measurement of the deflections during the experimental setup. See Chapter 3 – Experimental Investigation.

2.3.2 CALCULATION OF LATERAL HORIZONTAL DEFLECTION

It could be assumed at this stage that only the top flange of the crane girder and the rail would provide stiffness against the lateral horizontal deflection.

Based on this assumption, the horizontal deflection was calculated.

$$\Delta = \frac{Pl^2a}{24EI_{yy}}(3 - 4\alpha^2)$$

where:

P	= 20 kN
a	= 1800 mm
l	= 4500 mm
E	= 203,5 GPa (Modules of elasticity)
I_{yy}	= $I_{Girder,yy,TopFlange} + I_{Rail,yy} = 46,57 \times 10^6$
α	a/l

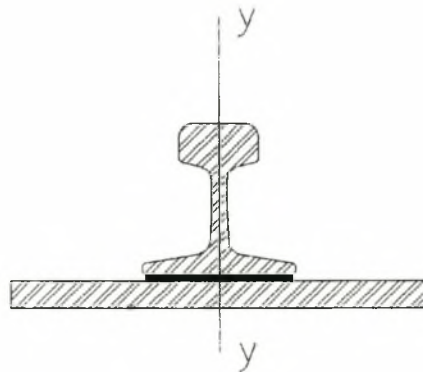


FIGURE 2.9: SECTION USED FOR LATERAL HORIZONTAL DEFLECTION

The calculated horizontal deflection was 7.56 mm.

2.3.3 CALCULATION OF STRESSES

The stresses in the flanges were calculated next. These forces and force effects can be summarised as the following:

- (1) Vertical wheel loads
- (2) Transverse wheel loads due to Misalignment

With these and the maximum moment due to the load in position 1 (refer to Chapter 3.2 *Test Loads* for the definition of load position 1) calculated to be equal to 180 kN.m known, the stresses in the top and the bottom flange could be calculated using the formulas below:

$$\sigma_{Bottom} = \frac{M_{xx} \bar{y}}{I_c} = -110,35 MPa$$

$$\sigma_{Top} = \frac{M_{xx} (h - \bar{y})}{I_c} = 35,44 MPa$$

The stresses due to misalignment were calculated, using only the top flange of the crane girder and the rail. The maximum moment due to the lateral horizontal load (misalignment) in load position 1 was equal to 36 kN.m.

$$\sigma_{Left} = \sigma_{Top} + \frac{M_{yy} \bar{y}}{I_{yy}} = 151,39 MPa$$

$$\sigma_{Right} = \sigma_{Top} - \frac{M_{yy} \bar{y}}{I_{yy}} = -80,51 MPa$$

A complete design can be seen in Appendix C.

2.4 SUMMARY OF THEORETICAL DESIGN RESULTS

The following results were used in determining the required type and size of the deflection meters (LVDTs¹) as well as the required capacity of the strain gauges. These results were obtained from the vertical load case in load position 1.

Maximum vertical deflection:	2.97 mm
Maximum compression stress in top flange:	35.44 MPa
Maximum tensile stress in bottom flange:	-110.35 MPa

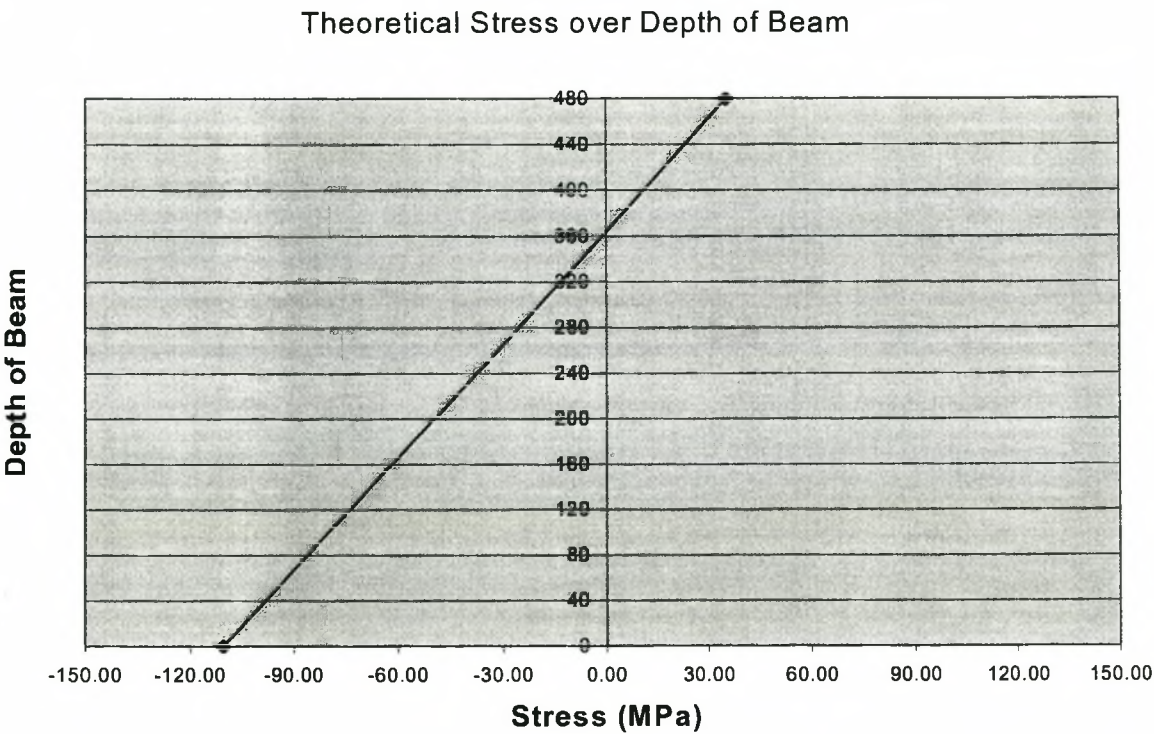


FIGURE 2.10: EXPECTED STRESS DISTRIBUTION OVER DEPTH OF GIRDER AT MIDSPAN

The deflection and stresses in the top flange due to the lateral horizontal load case of misalignment were:

Maximum horizontal deflection:	7.56 mm
Maximum compression stress in top flange:	151.39 MPa
Minimum tension stress in top flange:	-80.51 MPa

¹ LVDT – Linear variable displacement transducers

CHAPTER 3 - EXPERIMENTAL INVESTIGATION

3.1 INTRODUCTION

The purpose for the experimental investigation was to verify the Finite Element Model. With the selected load cases and combinations sufficient results were available to verify the Finite Element Model.

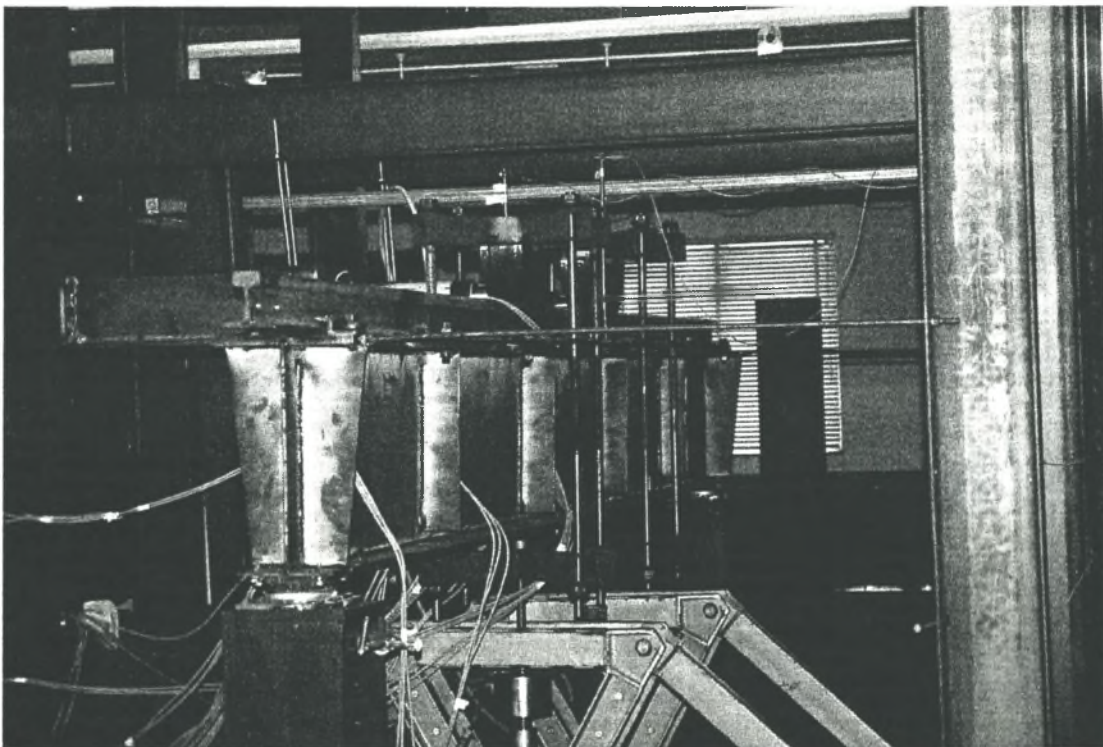
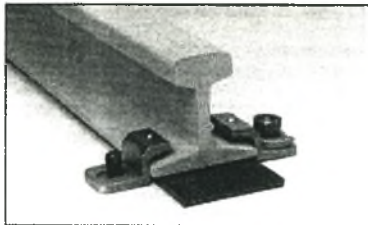


PHOTO 3.1: EXPERIMENTAL SETUP

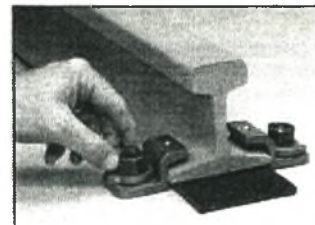
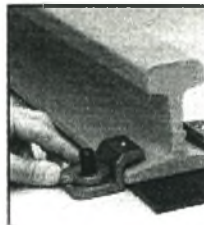
Two identical test beams were constructed to eliminate construction defects. By using the averages between the two beams, a more accurate representation of a beam without defects could be achieved.

The design drawings of the test beam were presented in Appendix D – *Design drawings for the construction of the experimental crane girder.*

The test beams were assembled by placing the bearing pad on the girder and then placing the 30-kg/m rail on top of the bearing pad. The clips were positioned and fixed as indicated on the photos below. The bolts were tensioned to a torque of 280 N.m. The following photos were from the web page of Gantrex[®], www.gantrex.co.com. For the spacing of the clips, refer to Chapter 2.2.2: *General assembly*.



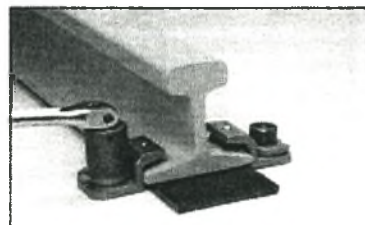
1. Position clip on bolt or stud.



2. Position self-locking cam. Install and lightly tighten nut.



3. Adjust self-locking cam to ensure tight contact between the rail and clip.



4. Tighten nut to required torque.

PHOTO 3.2: INSTALLATION PROCEDURES OF CLIPS

3.2 TEST LOADS AND LOAD POSITIONS

Following were a number of combinations of different load cases that were investigated in the experimental setup. For the determination of the values used for each load case, refer to Chapter 2.1.1: *Design Loads*.

Position 1

In the first position, the maximum moment affect was measured:

- Vertical loads at midspan
- Vertical loads at midspan with horizontal loads representing misalignment
- Vertical loads at midspan with horizontal loads representing skewing

Figure 3.1: *Position 1 – Layout and force effects*, indicates the layout of the loads in position 1 and also the load effects.

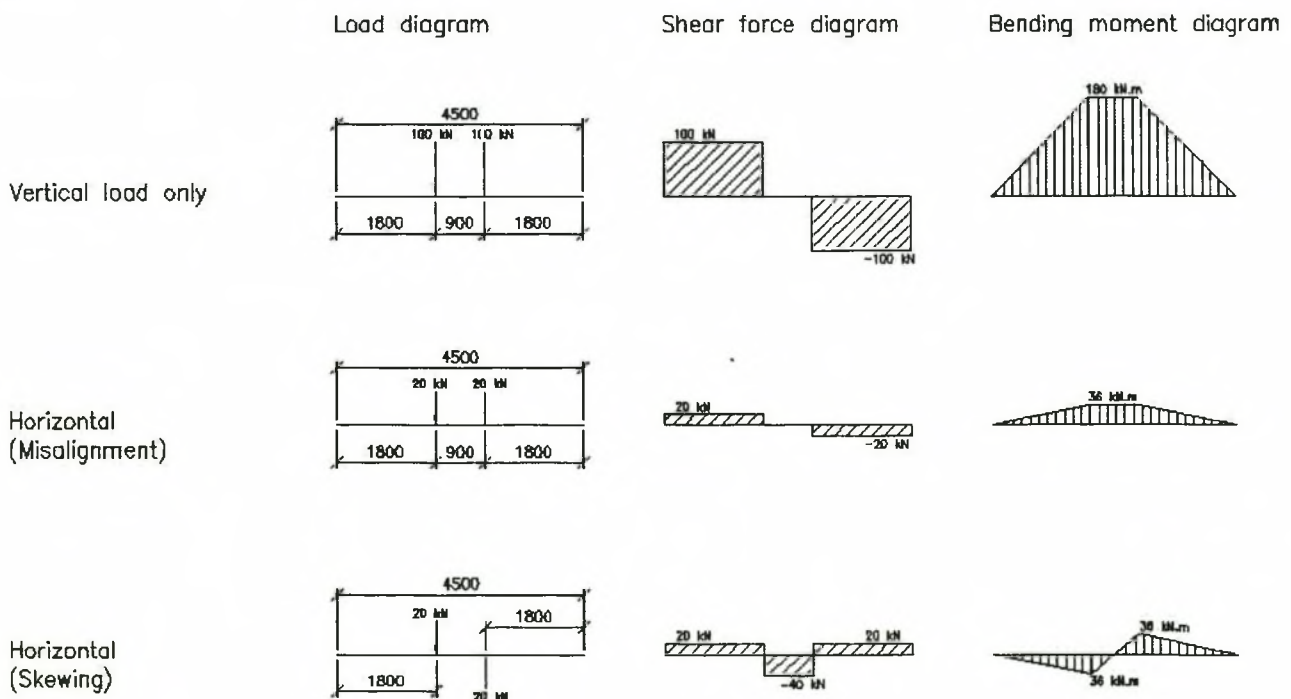


FIGURE 3.1: POSITION 1 – LAYOUT AND FORCE EFFECTS

Position 2

In the second position, the high shear effect was measured:

- Vertical loads at endspan
- Vertical loads at endspan with horizontal loads representing misalignment
- Vertical loads at endspan with horizontal loads representing skewing

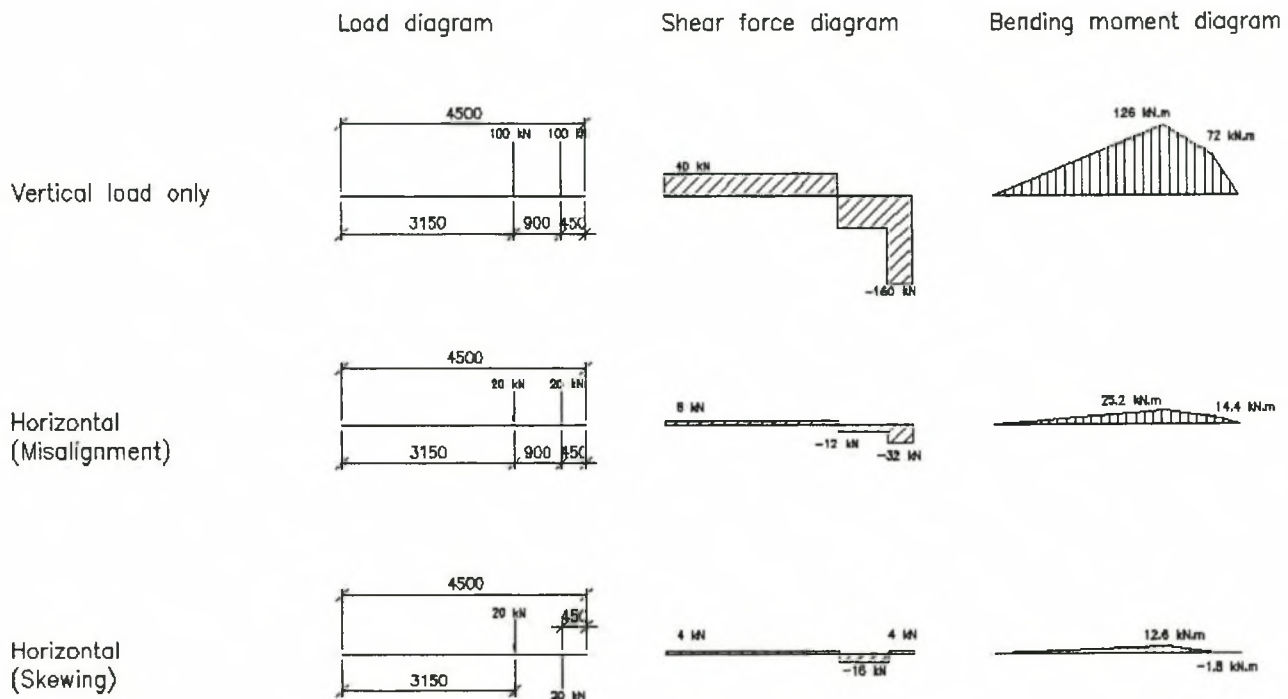


FIGURE 3.2: POSITION 1 – LAYOUT AND FORCE EFFECTS

3.3 TESTING APPARATUS

All the equipment used was available at the University of Stellenbosch, Civil Engineering Department. The following figure indicates the general layout of the experimental setup, with reference to the apparatus and loading equipment.

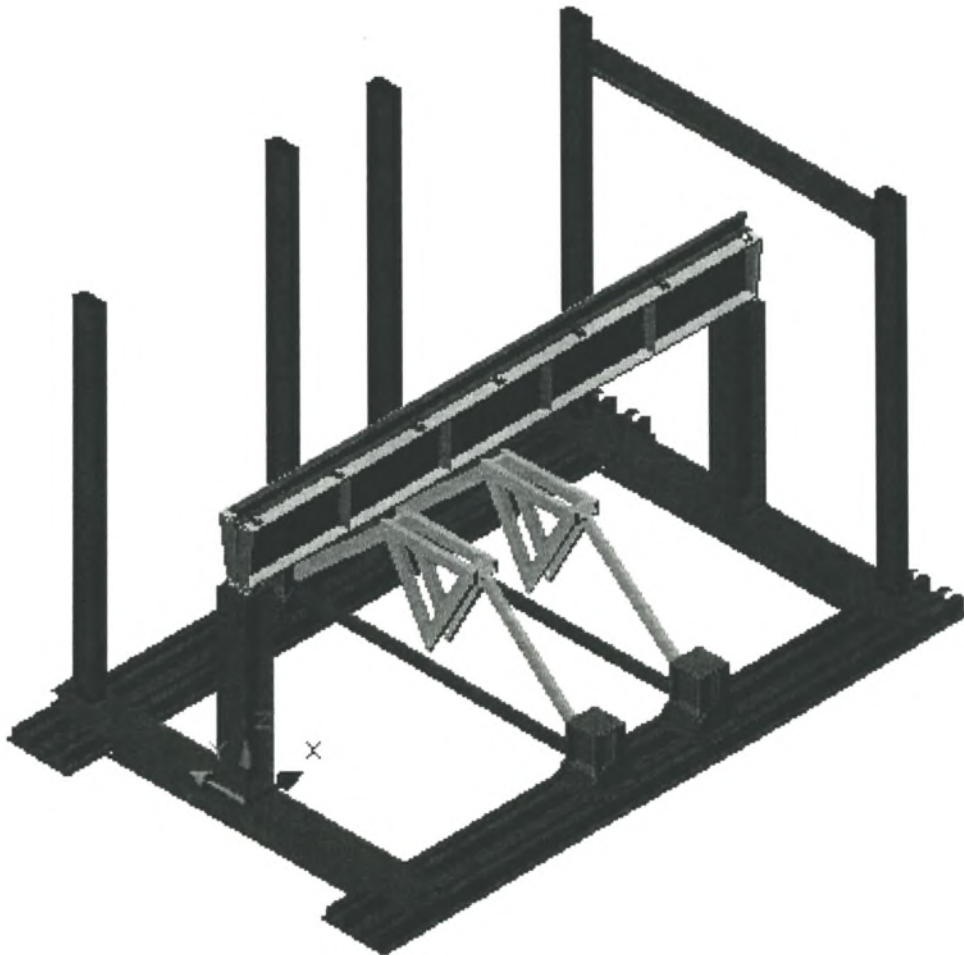


FIGURE 3.3: GENERAL ARRANGEMENT OF EXPERIMENTAL SETUP

(The above drawing can also be viewed on the attached CD, under the file name EXPERIMENTAL SETUP.dwg)

A support frame that can be used for the purpose of testing different systems was in place in the laboratory. This consists of rails, beams and columns. The support frame can be tied back to the main building.

Two stub columns were positioned 4500 mm apart. On top of these columns glacier bearings were used to represent pinned support boundary conditions.

Columns were then positioned on either side of the stub columns. These columns were fixed back to the main building and were used for lateral support of the top flange of the test girder at the support points.

Columns were also fixed on either side of the sway frame (see Section 3.3.1.2, Sway Frame). These columns were fixed back to the main building, and were used to apply horizontal forces at the position of the vertical loads.

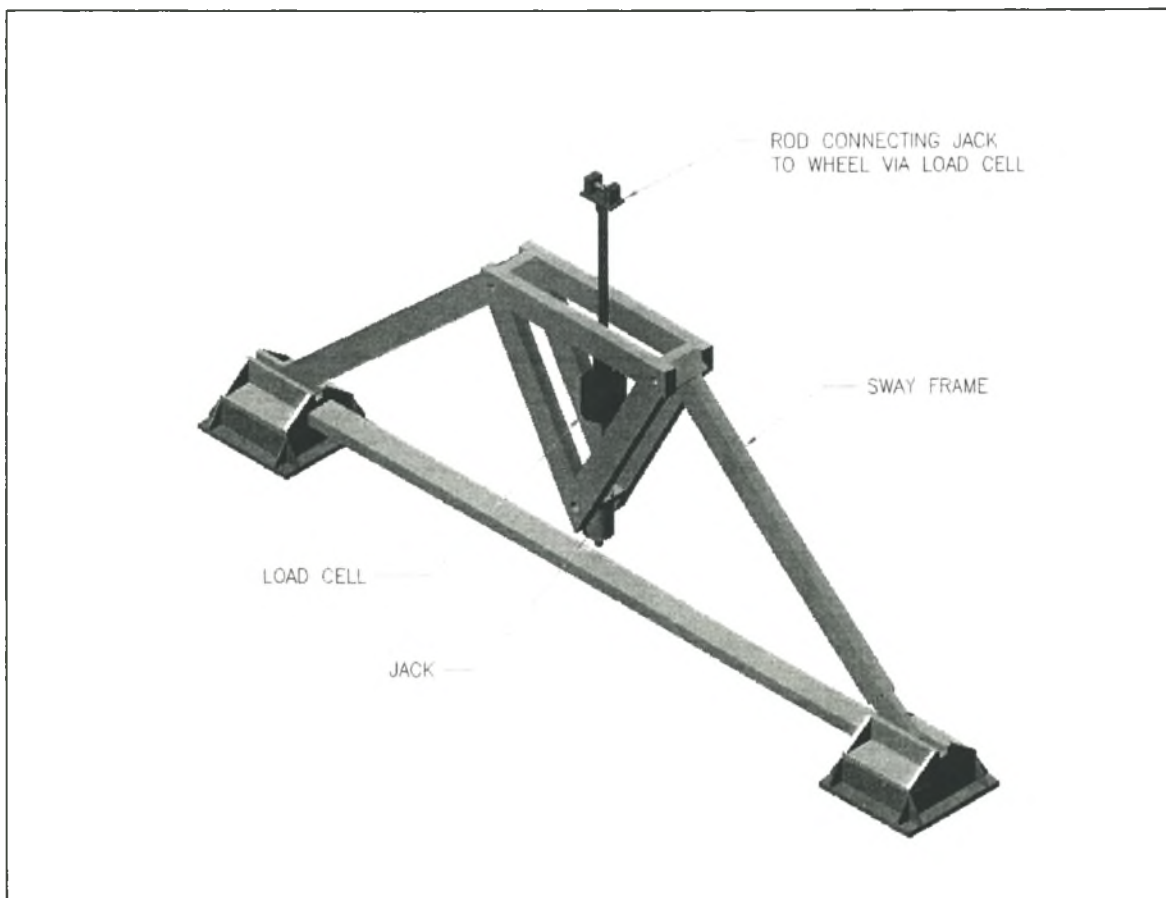
Even though the support frame was fixed back to the main building, no deflection measurement equipment was fixed to any member of the support frame.

3.3.1 LOADING EQUIPMENT

The following loading equipment was used.

3.3.1.1 Sway Frame

The Sway Frame was used to make sure that the vertical load was always vertical, independent of the possible rotation or sway of the test beam. This needed to be used since the theoretical design (Chapter 2) and the Numerical Model (Chapter 4) both used a constant vertical force, and did not take rotation into account. The sway frame also follows any horizontal deflection of the beam, thus always applying the load through the horizontal shear centre.



**FIGURE 3.4: SWAY FRAME WITH LOAD CELLS AND ACTUATORS
INDICATING SETUP**

3.3.1.2 Load Application Equipment

The load was transferred onto the test girder with a pump and load actuator system. The pump with load actuator was connected to the sway frame. The load cell was, in turn, fixed to the load actuator. A rod fixed to the wheel via a cross-and-rod system (see Figure 3.5: *Cross for distributing load to top of beam*) was connected through the load actuator and load cell.

- For the vertical loads, the Enerpac 60 ton RCH 603 actuator with the Enerpac Type P39 pump was used.
- For the horizontal loads, the Enerpac 20 ton RCH 202 actuator with the Enerpac Type P228 pump was used.

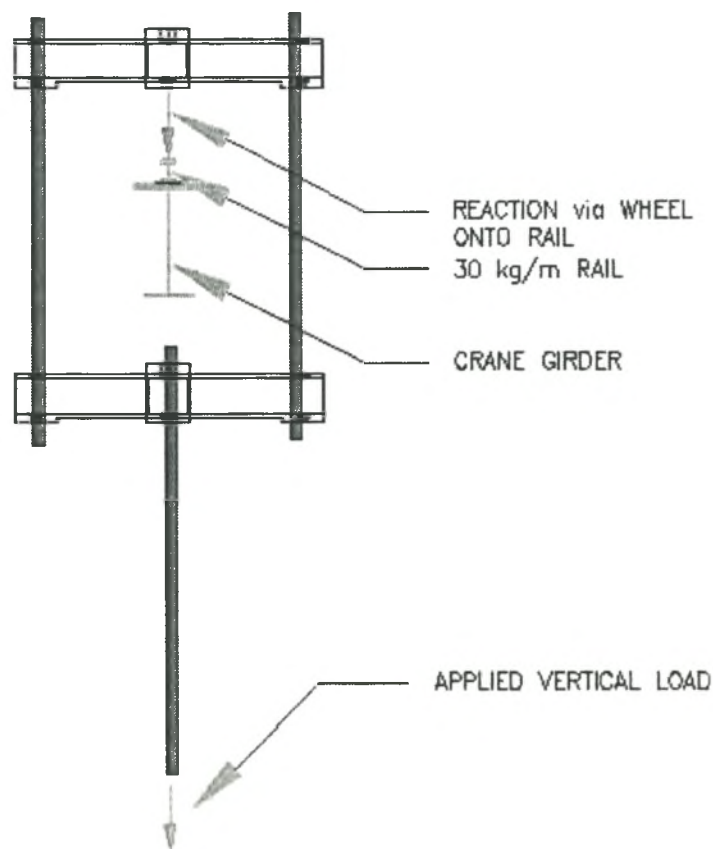


FIGURE 3.5: CROSS SYSTEM SHOWING PATH OF LOAD ONTO RAIL

3.3.2 MEASUREMENT INSTRUMENTATION

3.3.2.1 Amplifier

For the amplification of the electronic signal received from the measurement equipment, the Spiders with analogue/digital interface was used. The spiders come with computer software that enables the user to take readings of the change in the electronic signal directly in the required units, for example, taking measurements from load cells directly as kN. Once the test has been completed, the user can save the information in electronic format for later use.

A total of 64 amplified channels were available on the Spiders. All 64 were used.

A total of four channels were used for the load cells – refer to chapter 3.3.2.2: *Load cells*.

A total of four channels were used for the LVDT's – refer to chapter 3.3.2.3: *LVDT*.

A total of 48 channels were used for the strain gauges and strain rosettes – refer to Chapter 3.3.2.4: *Strain gauges*.

3.3.2.2 Load Cells

For the vertical loads, the HBM U2/20-ton load cells were used, and for the horizontal loads the ULP/S 5-ton load cell was used.

3.3.2.3 LVDT

LVDT was used to measure the displacement.

The positions of the LVDTs were fixed where the maximum deflection, vertical and horizontal, was expected. The positions can be seen in Figure 3.6: *Positions of LVDTs on test beam*.

3.3.2.4 Strain gauges

Strain gauges measure the change in strain on the surface of the member/structure being subjected to loads.

Two types of strain gauges were used:

- One directional strain gauges – KYOWA^{KFG-2-120-C1-11}
- Three directional strain rosettes - KYOWA^{KFG-5-120-D17-11}

The following questions were asked to determine the positions of the strain gauges on the test girder:

- Where will the maximum stresses occur in the girder?
- What will the stress distribution over the depth of the beam look like?
- What will the stress distribution look like over the width of the top and bottom flange under the load cases for skewing and misalignment?

The positions of the strain gauges were shown in Figure 3.7: *Position of strain gauges*.

The measured strains were converted to Von Mises Stresses. The following formulas indicate the process of manipulation to convert from the strains (as measured) to the Von Mises stresses.

Theory of Strain Rosettes:

Arrangements of gauge lines at a point in a cluster, as shown in Figure 3.8: *General Strain Rosette*, were called strain rosettes. If three strain measurements were taken at a rosette, the information was sufficient to determine the complete state of plane strain at a point.

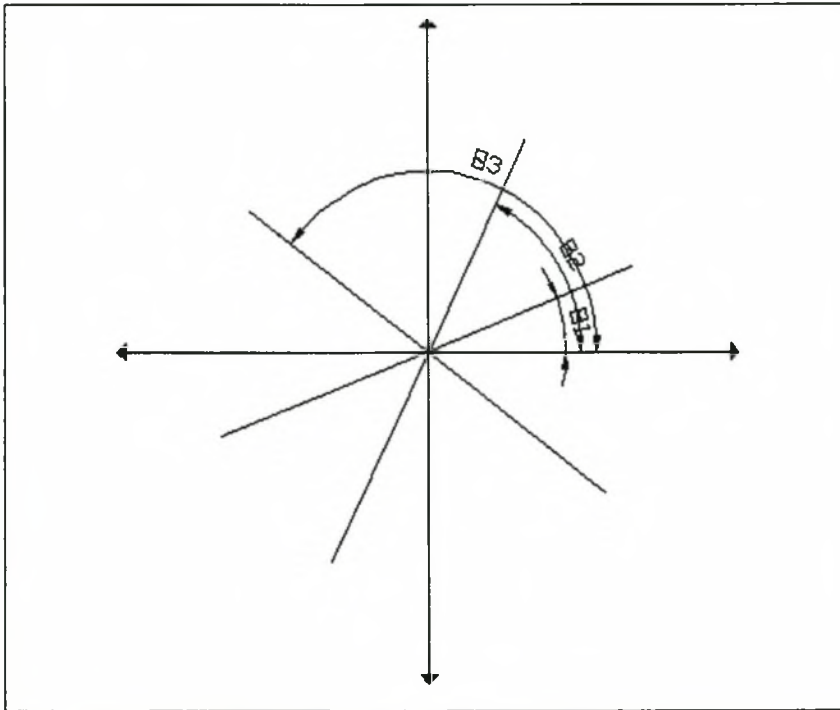


FIGURE 3.8: GENERAL STRAIN ROSETTE

If angles θ_1 , θ_2 and θ_3 , together with the corresponding strains ϵ_{θ_1} , ϵ_{θ_2} , and ϵ_{θ_3} , were known from measurements, three simultaneous equations can be written.

$$\epsilon_{\theta_1} = \epsilon_x \cos^2 \theta_1 + \epsilon_y \sin^2 \theta_1 + \gamma_{xy} \sin \theta_1 \cos \theta_1$$

$$\epsilon_{\theta_2} = \epsilon_x \cos^2 \theta_2 + \epsilon_y \sin^2 \theta_2 + \gamma_{xy} \sin \theta_2 \cos \theta_2$$

$$\epsilon_{\theta_3} = \epsilon_x \cos^2 \theta_3 + \epsilon_y \sin^2 \theta_3 + \gamma_{xy} \sin \theta_3 \cos \theta_3$$

To minimise computational work, the gauges in a rosette were usually arranged in an orderly manner. For example, KYOWA^{KFG-5-120-D17-11} strain rosettes (chosen to be used for this experimental setup) were 45° from one another.

By direct substitution into previous equations, it was found that, for this rosette;

$$\varepsilon_x = \varepsilon_0; \varepsilon_y = \varepsilon_{90}; \gamma_{xy} = 2\varepsilon_{45} - (\varepsilon_0 + \varepsilon_{90}).$$

The maximum normal strain was ε_1 ; the minimum was ε_2 . These were the principal strains, and no shear strains were associated with them. The directions of the normal strains coincide with the directions of the principal stresses. Thus, from Mohr's circle, the analytical expression for the principal strains is:

$$\varepsilon_{1or2} = \frac{\varepsilon_x + \varepsilon_y}{2} \pm \sqrt{\left(\frac{\varepsilon_x - \varepsilon_y}{2}\right)^2 + \left(\frac{\gamma_{xy}}{2}\right)^2}$$

In most problems where strain rosettes were used, it was necessary to determine the principal stresses at the point of strain measurement. In this problem, the normal stress on the surface was zero, i.e. $\sigma_z = 0$. Therefore, this was a plane stress problem. The principal stresses were:

$$\sigma_1 = \frac{E}{1-\nu^2} (\varepsilon_1 + \nu\varepsilon_2)$$

$$\sigma_2 = \frac{E}{1-\nu^2} (\varepsilon_2 + \nu\varepsilon_1)$$

The Elastic constants E and ν were determined earlier (see Chapter 2.1.3: *Material Properties*). Von Mises stresses could be calculated from the principle stresses using the following formula:

$$\sigma_{VonMises} = \sigma_x^2 + \sigma_y^2 - \sigma_x\sigma_y + 3\tau_{xy}^2$$

Where

$$\tau_{xy} = \left(\frac{1}{1+\nu}\right)\gamma_{xy}$$

and

$$\gamma_{xy} = 2\varepsilon_{xy} - (\varepsilon_{xx} + \varepsilon_{yy})$$

3.4 RESULTS OF EXPERIMENTAL INVESTIGATION

The results shown in Table 3.1: *Deflection measured during experimental investigation* were taken from a list of data created by the amplifiers (Spiders). The deflection measured for each load case was presented in table form below:

	Vertical Deflection at midspan	Horizontal Deflection of Top Flange	Horizontal Deflection of Bottom Flange
	mm	mm	mm
Vertical – Position 1	3.50	0.51	0.11
Misalignment – Position 1	4.05	-6.20	1.44
Skewing – Position 1	3.42	0.17	0.44
Vertical – Position 2	2.22	0.17	0.12
Misalignment – Position 2	2.21	-6.02	0.13
Skewing – Position 2	2.22	-1.85	0.96

TABLE 3.1: DEFLECTION MEASURED DURING EXPERIMENTAL INVESTIGATION

With the strain gauges and rosettes and the use of the amplifiers, the change in the strain against the applied load (also continuously measured) could be plotted for each strain gauge. The strains were converted to stresses and the Von Mises stresses were calculated for comparison with the results from the finite element analysis.

Some of the results from the experimental investigation can be seen on the following pages. More results were available in table form, and can be seen on the attached compact disc. (The file name on the disc was Von Mises Stresses.xls.)

The following two graphs were from the load in the first load position (representing maximum moment). The first graph indicates the stress distribution over the depth of the beam at midspan, while the second graph indicates the stress distribution over the width of the flanges.

From these graphs the following were clear:

- The horizontal load case for skewing does not impact on the overall beam stresses, but was a more local effect due to the two loads working in opposite directions.
- The drop in the stresses in the top flange during the skewing load case can be explained by the fact that strain gauges were used on the flanges, and the stresses in the longitudinal direction were reduced due to torsional effects on the top flange, while they were increased in the transverse direction. Due to the complexity of the stresses in the top flange, in hindsight, it might have been a better choice to use rosettes on the top flange as well.
- The horizontal load case for misalignment has a major impact on the top flange and minor impact on the rest of the beam.

The following results were the results from the second load position. As can be expected, the stresses due to bending were much lower than the stresses in the previous graphs for load position one.

The following can be seen clearly from the graphs:

- Slight variations were seen between the different load cases.
- A jump in the stresses can be seen in the central area of the beam; this can be explained due to the shear stresses in this region. Below was a photo^[5] from a previous study indicating the shear zone in the end panel.

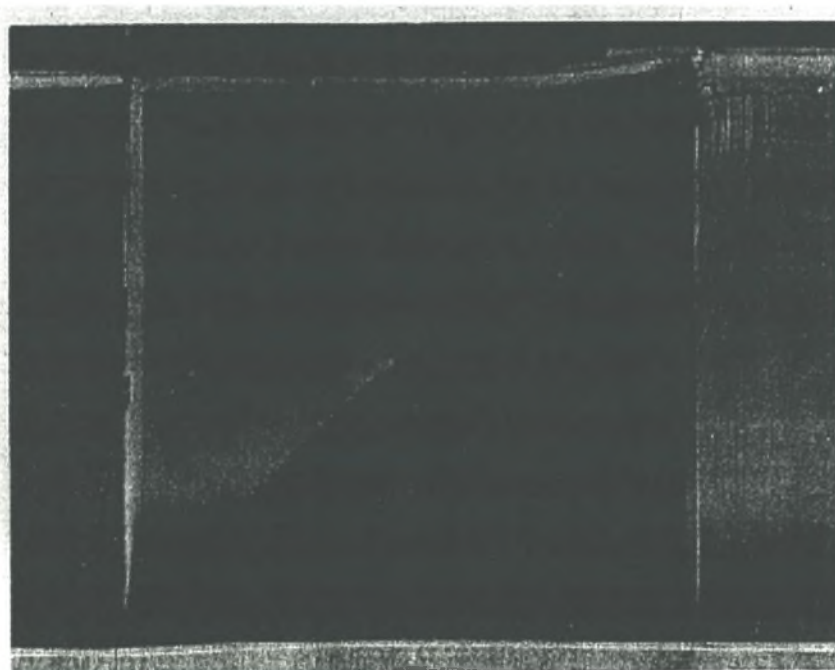


PHOTO 3.1: SHEAR ZONE IN END PANEL

^[5] AR Ingrassia, WH Gerstle, KI Mettam, P Wawrzynek & AK Hellier. "Cracking of welded crane runway girders: Physical testing and computer simulation". Iron and Steel Engineer. AISE. December 1985. P 46 – 52.

CHAPTER 4 - NUMERICAL MODEL

4.1 INTRODUCTION

A numerical model of the crane girder, pad and rail system was modelled using finite elements. The program used was the commercially available ABAQUS^[6].

The purpose of this model was to serve other students in numerically analysing different layouts and sizes of the crane girder. This numerical model needs to be verified so that further research can be done with confidence.

^[6] Abaqus, Version 5.8, Habbitt, Karlsson & Sorensen, Inc. Finite element analysis services (Pty) Ltd, The Waverley, Mowbray 7700.

4.2 TEST LOADS

The same load cases as discussed in Chapter 3 for the experimental model were used in the numerical model. The purpose was to compare the results from the different models.

These load cases were shown in Chapter 3.2: *Test Loads*.

The load cases were normally applied with two or more steps. The first step was the “assembly of the model”. In this step all the parts were put together, and the load for the clips (refer to Chapter 4.3: *Model Description*) were applied. In the second step, the vertical load was applied. And in the third step (if applicable) the transverse loads were applied.

4.3 MODEL DESCRIPTION

4.3.1 GENERAL

Classical beam or plate theories were not suited for modelling the crane girder-pad-rail interaction problem. For this reason, it was decided to model the whole system in 3D. The model consisted of a rail, elastomeric pad, and the crane girder. The clips were omitted (a load representing the pressure exerted by the clips onto the rail were used – this reduced the size and complexity of the model considerably).

Also, instead of modelling a wheel through which the loads were to be applied, only point loads were applied onto the rail. It was believed that the difference in the stresses on the top flange, when the loads were applied with the wheel, versus when it was applied with a point load, was negligible. The reason for this assumption was due to the path that the load travels (Rail to pad to top flange).

All solid elements used were 20 node hexagonal, quadratic bricks.

As explained earlier, material tests were performed on samples of rail, elastomeric pad and the crane girder steel (see Appendix B). For the properties used in the numeric model, please refer to Chapter 2.1.3: *Material Properties*.

The model was constructed with 20-node solid hexagonal brick elements. These elements had mid-side nodes and were based on quadratic shape functions. Most 3-D structural problems that involve bending can be modelled very accurately with a modest number of elements that deform quadratically. Other quadratic elements, like the 10-node tetrahedron and the 15-node wedge, give similar results but lead to larger computational workloads.

These elements made up the different parts (crane girder, Gantrex pad and rail). These parts were held together by constraint functions along the interfaces.

4.3.2 CRANE GIRDER

The crane girders, as used in the experimental investigation, were modelled using the finite element method. These measurements were given in Appendix D – *Design Drawings for the Construction of the Experimental Crane Girder*. For the fillet welds, a 10 mm chamfer was included in the steel layout. The drawing below indicates the finite element mesh of the crane girder with web stiffeners.

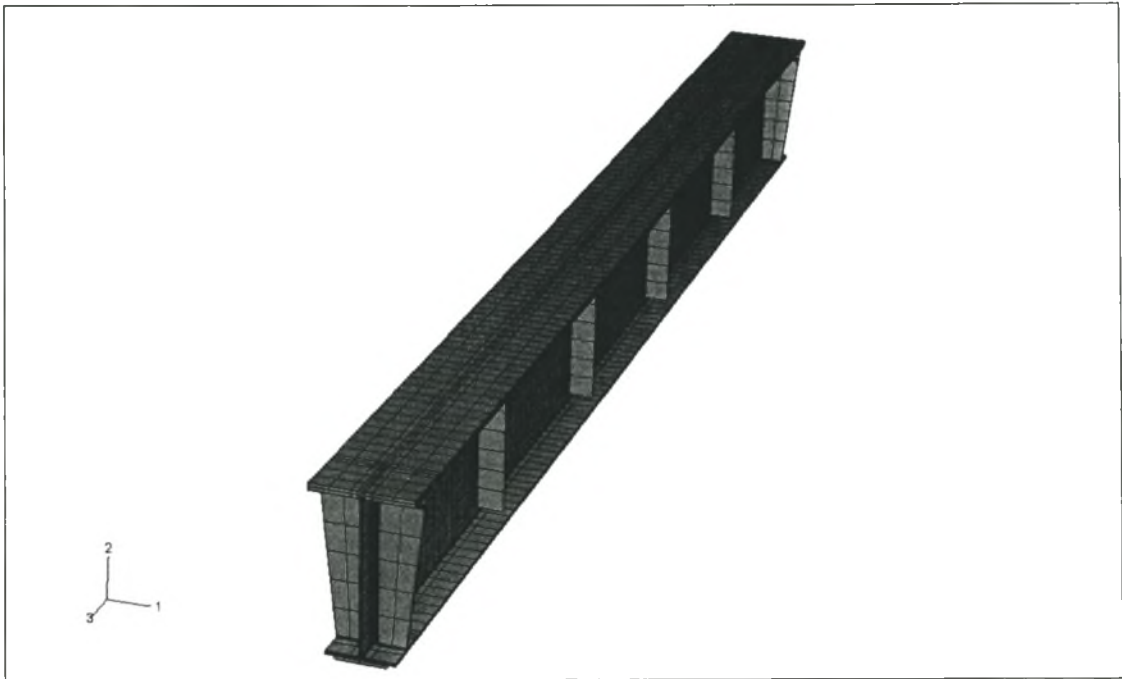


FIGURE 4.1: CRANE GIRDER MESH LAYOUT

The beam consisted of a total of eight (four on each size) intermediate stiffeners and four (two on each side) bearing stiffeners. The model size can be summarised as follows:

	No. of Nodes	No. of Elements	No. of DOF
Beam with Stiffeners	39,263	6,528	117,789

TABLE 4.1: CRANE GIRDER MODEL SIZE

4.3.3 GANTREX PAD

Between the rail and the girder was an elastomeric rail pad (Gantrex MK6). This pad was also modelled to give a more accurate representation of the real setup. The size of the pad in the model was:

- Thickness: 7 mm
- Width: 98 mm
- Length: 4500 mm

The finite element mesh for the elastomeric pad was shown in Figure 4.2: *Gantrex MK6 elastomeric rail pad mesh layout*.

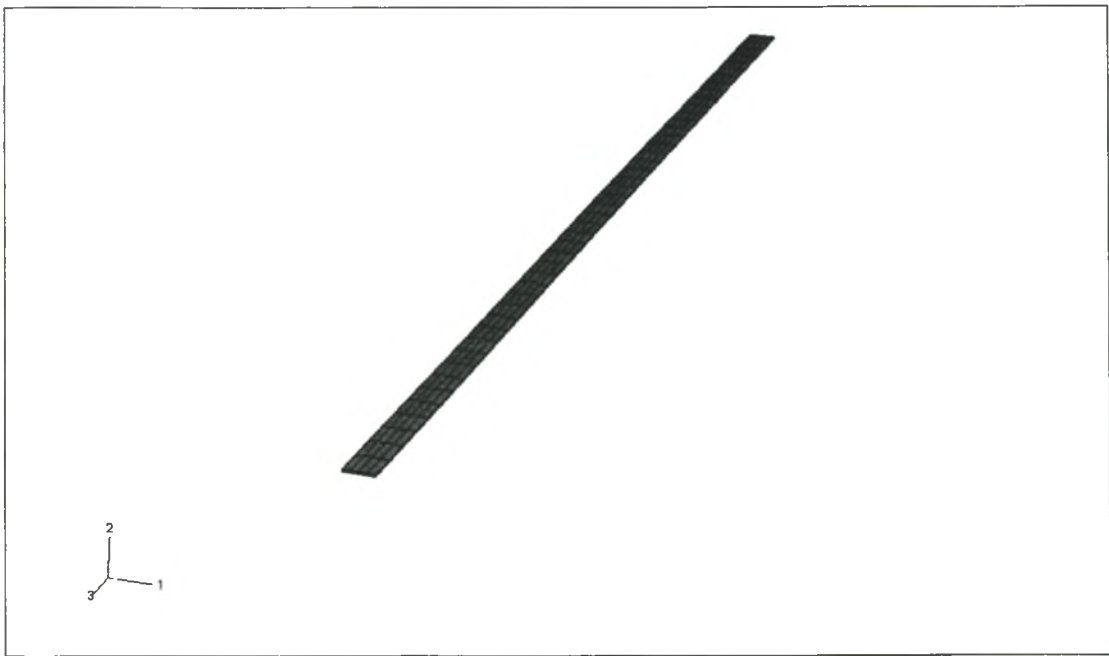


FIGURE 4.2: GANTREX MK6 ELASTOMERIC RAIL PAD MESH LAYOUT

	No. of Nodes	No. of Elements	No. of DOF
Pad	1,508	180	4,524

TABLE 4.2: ELASTOMERIC PAD MODEL SIZE

4.3.4 RAIL

It was also decided to model the rail to ensure a representative distribution of the point loads through this member. The rail used in the model was a 30 kg/m rail and the dimensions were as follows:

Length: 5000 mm
Size: See figure below.

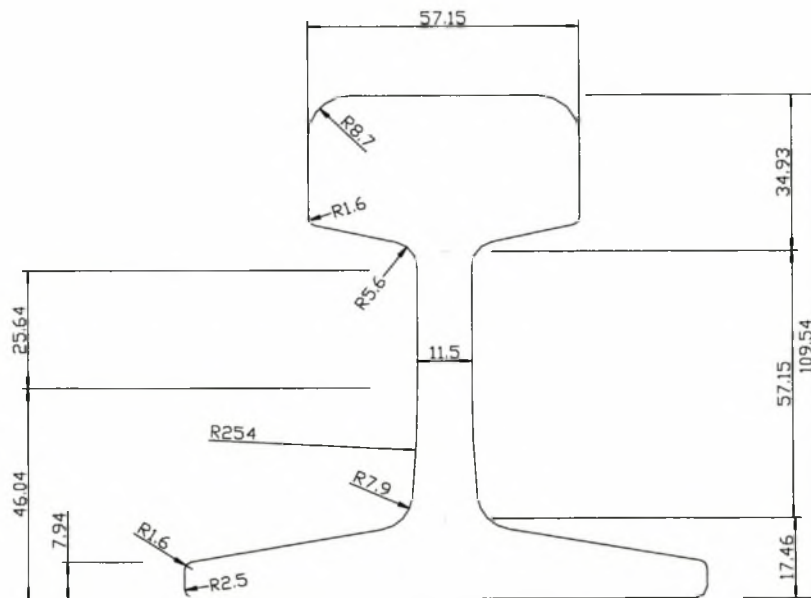


FIGURE 4.3: LAYOUT OF 30 kg/m RAIL

The finite element mesh of the rail was shown in Figure 4.4: *30 kg/m rail mesh layout*.

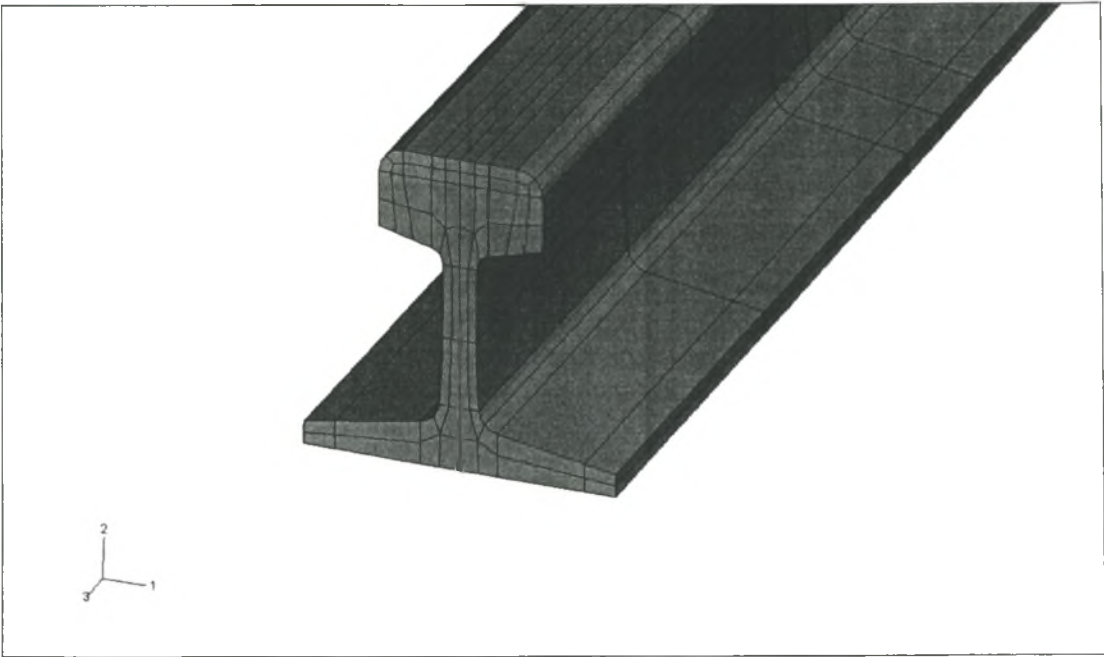


FIGURE 4.4: 30 kg/m RAIL MESH LAYOUT

	No. of Nodes	No. of Elements	No. of DOF
Rail	17,147	3,300	51,441

TABLE 4.3: CRANE GIRDER MODEL SIZE

4.4 MODEL SIZE AND COMPUTATIONAL LIMITS

It was necessary to limit the size of the model so that no unrealistic computational times were needed to solve a model without compromising the accuracy of the results. The size of a finite element model was usually defined in terms of the total number of degrees of freedom. The size of the model that was constructed had 3786 degrees of freedom. This translated to about six hours CPU time for a machine with 733 MHz clock speed and 1000 Mbytes Ram.

PROBLEM SIZE

NUMBER OF ELEMENTS	9728
NUMBER OF NODES	56372
NUMBER OF NODES DEFINED BY THE USER	56372
TOTAL NUMBER OF VARIABLES IN THE MODEL	169116

4.5 RESULTS OF NUMERICAL INVESTIGATION

The following figures indicate the Von Mises stresses over the flanges and depth of the beam, as shown in Chapter 3: *Experimental Investigation*, but also included in this section were figures of the different loaded beams. See Figure 4.7 to Figure 4.9.

Firstly, the deflections determined during the numerical investigation in table form are:

	Vertical Deflection at midspan	Horizontal Deflection of Top Flange	Horizontal Deflection of Bottom Flange
	mm	mm	mm
Vertical – Position 1	3.86	0.01	0.01
Misalignment – Position 1	3.97	-8.55	1.66
Skewing – Position 1	3.85	0.01	0.01
Vertical – Position 2	1.81	0.01	0.01
Misalignment – Position 2	1.80	-3.57	-2.90
Skewing – Position 2	1.79	-1.18	1.39

TABLE 4.4: DEFLECTION DETERMINED DURING NUMERICAL INVESTIGATION

More results than those shown below were available in table form, and can be viewed on the attached compact disc under the file name Von Mises Stresses.xls.

Figure 4.5 and Figure 4.6 were the results from the load in position 1 (refer to chapter 3.2: *Test loads and load positions*). The first graph indicates the stress distribution over the depth of the beam at midspan, while the second graph indicates the stress distribution over the width of the flanges.

From these graphs the following were clear:

- The horizontal load case for skewing does not impact on the overall beam stresses, but was a more local effect due to the two loads working in opposite directions. This local affect can be seen clearly in Figure 4.7 to Figure 4.9.
- The horizontal load case for misalignment has a major impact on the top flange and a minor impact on the rest of the beam.

Figure 4.10 shows the results from the load in position 2 (refer to Chapter 3.2: *Test loads and load positions*). As could be expected, the stresses due to bending were also much lower than the stresses in the previous graphs for load position one.

The following can be seen clearly from the graphs:

- Slight variations between the different load cases
- A jump in the stresses in the central area of the beam; this can be explained as due to the shear stresses in this region. This was explained in Chapter 3.4: *Results*.

CHAPTER 5 - VERIFICATION OF NUMERICAL MODEL

5.1 INTRODUCTION

The numerical model has to be verified for future research. While the theoretical investigation was used to size the test beam and determine expected results for the experimental investigation, only the experimental investigation will be used to verify the numerical model. By comparing the following results, the numerical model can be assumed to be correct. The data to be compared were as follows:

- Vertical deflection under vertical wheel loads at midspan
- Horizontal deflection under vertical and horizontal wheel loads at midspan
- Von Mises stresses on bottom flange under vertical and horizontal wheel loads
- Von Mises stresses on Top flange under vertical and horizontal wheel loads
- Von Mises stresses through depth of beam under vertical and horizontal wheel loads at midspan

5.2 COMPARISON OF RESULTS

For purposes of clarity, the comparisons were presented in graph form. (More data were available on the attached compact disc; refer to file Von Mises Stresses.xls).

Comparison between the experimental and numerical deflections:

	Experimental	Numerical	Deviation between Experimental and Numerical
	mm	mm	%
Vertical – Position 1	3.50	3.86	9.3
Misalignment – Position 1	4.05	3.97	2.0
Skewing – Position 1	3.42	3.85	11.2
Vertical – Position 2	2.22	1.81	18.5
Misalignment – Position 2	2.21	1.80	18.6
Skewing – Position 2	2.22	1.79	19.3

TABLE 5.1: DEFLECTION COMPARISON

The following three graphs were from the load in the first position (refer to Chapter 3.2: *Test loads and load positions*). Figures 5.1 and 5.2 indicate the stress distribution over the depth of the beam at midspan, while Figure 5.3 indicates the stress distribution over the width of the flanges. These stresses were for both the experimental and numerical models and it can be seen that the results of the different models compare well. Additional graphs and tables showing these results can be viewed on the attached compact disc (refer to the file Von Mises Stresses.xls).

CHAPTER 6 - EXTRACTION OF ADDITIONAL RESULTS FROM NUMERICAL MODEL

6.1 INTRODUCTION

The purpose of this project was to design and verify a numerical model of a crane girder for further research.

Warren^[7] was currently doing another research project through which the fatigue stresses due to eccentric loads were investigated. These stresses were determined theoretically, but needed to be determined numerically as well. The model that was created assisted in determining stresses at the required positions using the finite element method.

It should however be noted that the type of elements chosen and the node layout worked well for the purpose of the model. But it is the responsibility of the researcher using this model to make sure that it is also applicable for his/her requirements.

^[7] Juliet Warren, Fatigue research of Crane Girders when subjected to Loads imposed by Overhead Travelling Cranes.

6.2 ADDITIONAL ANALYSIS

The numerical model was loaded with two additional loads as can be seen in the following figure:

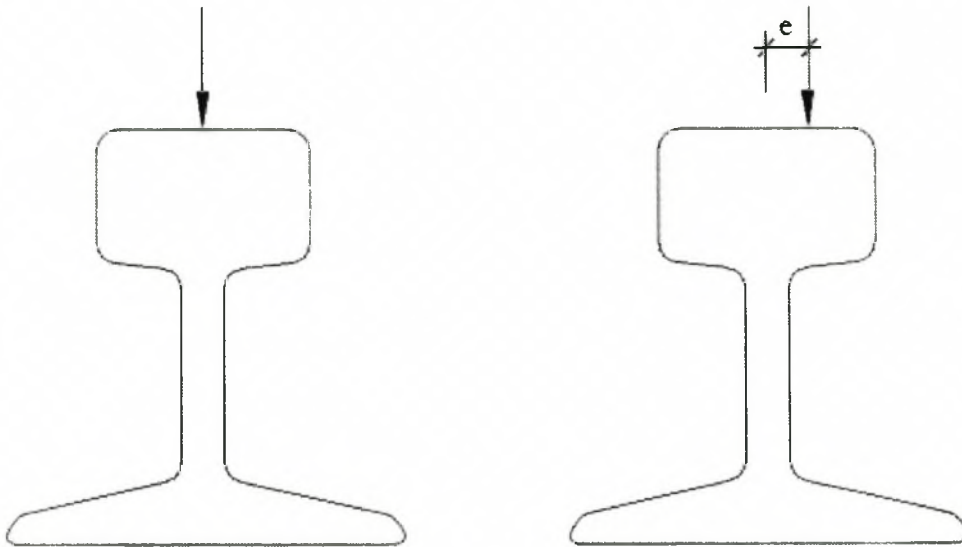


FIGURE 6.1: ADDITIONAL LOAD POSITIONS FOR ADDITIONAL RESEARCH

The purpose of these load positions was to determine the effect on the stresses in the weld connecting the top flange and the web of the crane girder. Both these point loads were applied at midspan.

6.3 ADDITIONAL RESULTS

The researcher would need to be familiar with Abaqus should he need to do further analyses. The model, however, was implemented in such a way that the researcher can easily create further steps for additional load combinations.

CHAPTER 7 - CONCLUSIONS

The investigation into the top flange and web deformation in a crane girder panel was a success. This can be stated due to the good comparisons between the experimental and numerical results. These comparisons were however not achieved without some difficulty. Some of the problems experienced during the experimental investigation and how they were overcome, can be briefly noted:

- Lateral support of the experiment:

A support frame supported the complete experiment setup. It was experienced that this frame gave insufficient resistance to lateral loads. Thus originally when a horizontal load was applied to the test beam, the support frame would give way due to the reaction forces. This problem was overcome by tying the support frame back to the main building.

- Measurement equipment supports:

Due to the slenderness of the support frame, additional supports were designed for the measurement equipment. Reference to the deflection meters was made here.

If a recommendation to the University of Stellenbosch can be made, it will be the following:

- Network points in the laboratory:

The majority of the equipment was up to date with the exception of sufficient storage and transfer of data. The researcher needs portable storage devices to be able to transport data from the laboratory to the workstation where this information will be used. These network points will also enable lecturers and other researchers to review experiments by remote.

Other researchers can use the numerical finite element model with confidence. This will enable the researchers to do relative quick and inexpensive investigation in the behavior of a crane girder panel when subjected to loads imposed by an overhead traveling crane. Examples of these can be summarized as follows:

- Stresses and strains at the top flange and web connection
- Stresses and strains at the top flange and web stiffener connection
- Stresses and strains at the web and web stiffener connection
- Stresses and strains at the crane girder supports
- Horizontal deflection of the crane girder panel
- Vertical deflection of the crane girder panel
- Rotation of the crane girder panel

All of the above would be difficult to determine without either an experimental investigation or this finite element model. The model was also designed with this in mind. The researcher will find that the model has been put together to allow changes without difficulty.

CHAPTER 8 - REFERENCES

- 1 SABS 0160 – 1989, South African Bureau of Standards, Private Bag X191, Pretoria.
- 2 A.R. Perez Winkler, An Investigation of Overhead Crane Wheel/Rail/Girder Interaction, University of Stellenbosch, 2003.
- 3 SASCH, South African Steel Construction Handbook, Third Edition, 1997.
- 4 SABS 0162 – 1: 1993, South African Bureau of Standards, Private Bag X191, Pretoria.
- 5 AR Ingrassia, WH Gerstle, KI Mettam, P Wawrzynek and AK Hellier. “Cracking of welded crane runway girders: Physical testing and computer simulation”. Iron and Steel Engineer. AISE. December 1985. P 46–52.
- 6 Abaqus, Version 5.8, Habbitt, Karlsson & Sorensen, Inc. Finite element analysis services (Pty) Ltd, The Waverley, Mowbray 7700.
- 7 Juliet Warren, Fatigue research of Crane Girders when subjected to Loads imposed by Overhead Travelling Cranes, University of Stellenbosch, 2004.
- 8 J Collins, R Mackenzie, K Pospisek and W James. “The design and Long Term Performance of Heavy Duty Crane Beams”. SA institute of steel construction. P 473–487.
- 9 AR Ingrassia, WH Gerstle, KI Mettam, P Wawrzynek and AK Hellier. “Cracking of welded crane runway girders: Physical testing and computer simulation”. Iron and Steel Engineer. AISE. December 1985. P 46–52.

- 10 KH Frank and JW Fisher. "Fatigue Strength of Fillet Welded Cruciform Joints".
Journal of the Structural Division. September 1979. P 1727–1741.
- 11 HS Reemsnyder and DA Demo. "Fatigue cracking in welded crane runway girders:
causes and repair procedures". Iron and Steel Engineer. April 1978. P 52–56.
- 12 DA Demo and JW Fisher. "Analysis of Fatigue Welded Crane Runway Girders".
Journal of the Structural Division. P 919–933.
- 13 G Maas. "Investigations Concerning Craneway Girders". Iron and Steel Engineer.
March 1972. P 49–58.
- 14 AG Senior and TR Gurney. "The design and service life of the upper part of
welded crane girders". The Structural Engineer. October 1963. P 301–312.
- 15 F Sedlmayer. "Stresses on top Flanges of Crane Girders Caused by Crab Wheel
Loads". Iscor Library. April 1973.
- 16 A Korvink, JM Barsom and R Bjorhovde. "Deformation Capacity Demands of
Structural Steel Elements". Journal of Constructional Steel Research. 1998.
46:1-3. Paper No. 130.
- 17 F Lagomaggiore. "Numerical analysis of the stresses in girders for heavy-duty
overhead crane runways". Costruzioni Metalliche. 1981. N.6. P 328 – 339.

CHAPTER 9 - ACKNOWLEDGEMENTS

Firstly, I should like to thank the University of Stellenbosch for the opportunity to do this research.

I should like to thank Prof. P.E. Dunaiski of the Department of Civil Engineering at the University of Stellenbosch for his guidance and support.

I should like to thank Mr H. Barnard, of the Department of Civil Engineering at the University of Stellenbosch; without his help this project would not have been possible.

I should like to thank Messrs A. Rossouw, L. Frederiks and A. Layman for the physical help during the construction and setup of the experiments.

Finally, I should like to thank my parents for their continuous support and motivation.

APPENDIX A - TYPICAL DIMENSIONS OF CRANES AT SALDANHA STEEL

The following pages contain a summary of the typical dimensions of cranes at the Saldanha Steel plant. These dimensions were used to determine representative dimensional ratios for the design of the experimental girder.

**APPENDIX B - MATERIAL PROPERTIES OF STEEL USED
FOR THE MANUFACTURING OF THE
CRANE GIRDER**

Material Tests on Steel.

Test pieces were manufactured from the top flange, bottom flange and web of the beam. The dimensions and test procedures were in accordance with SABS ISO 6892:1984². The dimensions of the test pieces were as follows.

Section	Dimensions		
	L (mm)	b (mm)	t (mm)
Top Flange	300	40	20
Bottom Flange	300	40	10
Web	300	40	8

TABLE B1: TEST SPECIMEN SIZES (STEEL)

The results of these tests were given in Figure B2: *Stress Strain Curve*. In summary however, the following can be noted:

E-Modules 203.50 GPa
Yield Stress 310.50 MPa

² SABS ISO 6892:1984 Metallic materials – Tensile testing

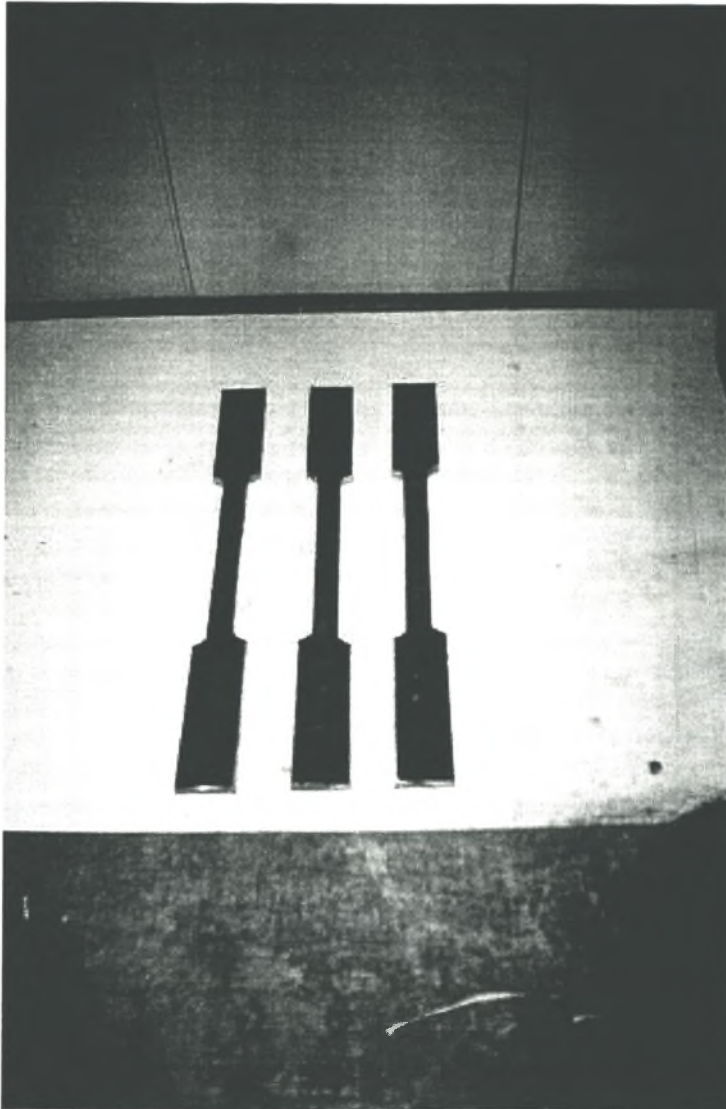


PHOTO B1: TEST PIECES BEFORE TESTING

APPENDIX C - DESIGN FILE FOR THE CRANE GIRDER

The following design was created using commercially available software called MathCAD 2000 Professional.

Crane Girder Design
2004/07/27

Crane Data

General Crane Properties:

NumWheels := 4

NumSideWheels := 2

CraneClass := 4

Rail := 30 $\left(\frac{\text{kg}}{\text{m}}\right)$

Sasch: Parr 10.7

Static wheel load factor:

C := 0.29

$\phi_{\text{Wheel}} := 265$

$\phi_{\text{Wheel}} = 265 \quad (\text{mm})$

$W := C \cdot \phi_{\text{Wheel}}^3 \cdot 10^3$ (Maksimum on each wheel)

$W = 76850 \quad (\text{N})$

Crane Wheel Forces

Vertical Wheel Forces:

$V_{\text{max}} := W$

$V_{\text{max}} = 76850 \quad (\text{N})$

SABS 0160: 1989
Parr 4.4.2

LLF := 1.0 (Serviceability factor)

LLF = 1.0

SABS 0160-1989
Parr 4.4.2

DLF := 1.1 (Serviceability factor)

DLF = 1.1

SABS 0160:1989,
Parr 5.7.3

IFV := 1.3

IFV = 1.3

$V_i := \text{IFV} \cdot V_{\text{max}}$ (Unfactored wheel force with impact)

$V_i = 99905 \quad (\text{N})$

$V_u := \text{LLF} \cdot V_{\text{max}}$ (Factored wheel force without impact)

$V_u = 76850 \quad (\text{N})$

$V_{ui} := \text{LLF} \cdot \text{IFV} \cdot V_{\text{max}}$ (Factored wheel force with impact)

$V_{ui} = 99905 \quad (\text{N})$

$V_{ui} := 100000$ (Rounded up)

$V_{ui} = 100000 \quad (\text{N})$

Crane Girder Design
Page: 2

Transverse Wheel Forces:

(1) Acceleration and Braking of Crab:

SABS 0160:1989,
Parr 5.7.4

$$X_1 := 0.2$$

(Load Scale factor for class 4 cranes)

$$X_1 = 0.2$$

$$M_1 := V_{ui}$$

$$M_1 = 100000 \quad (N)$$

$$P_{t1n} := X_1 \cdot M_1$$

$$P_{t1n} = 20000 \quad (N)$$

$$P_{t1s} := LLF \cdot P_{t1n}$$

$$P_{t1s} = 20000 \quad (N)$$

(2) Misalignment of Crane Wheels of Rails:

SABS 0160:1989,
Parr 5.7.4

$$X_2 := 0.2$$

(Load Scale factor for class 4 cranes)

$$X_2 = 0.2 \quad (N)$$

$$M_2 := V_{ui}$$

$$M_2 = 100000 \quad (N)$$

$$P_{t2n} := X_2 \cdot M_2$$

$$P_{t2n} = 20000 \quad (N)$$

$$P_{t2s} := LLF \cdot P_{t2n}$$

$$P_{t2s} = 20000 \quad (N)$$

(3) Skewing of Crane:

SABS 0160:1989,
Parr 5.7.4

$$X_3 := 1.0$$

This will normally be 1.5, but due
to capacity of jacks 1.0 will be used)

$$X_3 = 1$$

$$P_{t3n} := X_3 \cdot P_{t2n}$$

$$P_{t3n} = 20000 \quad (N)$$

$$P_{t3s} := LLF \cdot P_{t3n}$$

$$P_{t3s} = 20000 \quad (N)$$

Longitudinal Wheel Forces:

SABS 0160:1989,
Parr 5.7.5

$$X_L := 0.10$$

$$X_L = 0.1$$

$$P_{Ln} := X_L \cdot \text{NumSideWheels} \cdot V_{\max}$$

$$P_{Ln} = 15370 \quad (N)$$

$$P_{Ls} := LLF \cdot P_{Ln}$$

$$P_{Ls} = 15370 \quad (N)$$

Crane Rail Assembly

Rail Size:

Size := 30 $\left(\frac{\text{kg}}{\text{m}}\right)$

SASCH Parr 2.96

$F_{\text{RailBase}} := 109.5 \text{ (mm)}$

$F_{\text{RailBase}} = 109.5 \text{ (mm)}$

Rail Pads:

Gantrex:

$t_{\text{pad}} := 7 \text{ (mm)}$

Elastometric Pad

$t_{\text{pad}} = 7 \text{ (mm)}$

Gantrex:

Rail Clips:

Use Boltable Clips in order to allow for
Clip spacing adjustment.

Clip Series: StelCam13
Lateral Adjustment = 10 mm
Bolt Diameter = 12 mm
Resistance to lateral side thrust = 34.41

$\text{TrClipBltW} := F_{\text{RailBase}} + 25.4 \cdot \frac{15}{7}$

$\text{TrClipBltW} = 163.929 \text{ (mm)}$

$\text{MinRSW} := F_{\text{RailBase}} + 25.4 \cdot \frac{17}{4}$

$\text{MinRSW} = 217.45 \text{ (mm)}$

Crane Girder Design

Preliminary Girder Property Selection:

Design Parameters:

SAISCH P10.17

Profile: Monosymmetric I-Section use
no intermediate stiffeners, use no surge
plate, use structural steel - grade 300WA

$F_y := 300 \text{ (MPa)}$

$F_y = 300 \text{ (MPa)}$

$\phi_b := 0.9$

$\phi_b = 0.9$

$\nu := 0.3$

$\nu = 0.3$

$E := 203.5 \cdot 10^3 \text{ (MPa)}$

$E = 203.5E+003 \text{ (MPa)}$

$G := \frac{E}{2 \cdot (1 + \nu)}$

$G = 78E+003 \text{ (MPa)}$

SASCH Table 13.11

$\gamma_{300WA} := 7850 \left(\frac{\text{kg}}{\text{m}^3} \right)$

$\gamma_{300WA} = 7850 \left(\frac{\text{kg}}{\text{m}^3} \right)$

Crane Girder Properties:

$L_{CG} := 4500 \text{ (Crane Girder Span)}$

$L_{CG} = 4500 \text{ (mm)}$

Crane Girder Top Flange Width:

$$t_{fb} := \begin{cases} 150 & \text{if } \text{MinRSW} \leq 150 \\ 200 & \text{if } 150 < \text{MinRSW} \leq 200 \\ 250 & \text{if } 200 < \text{MinRSW} \leq 250 \\ 300 & \text{if } 250 < \text{MinRSW} \leq 300 \\ 350 & \text{if } 300 < \text{MinRSW} \leq 350 \\ 400 & \text{otherwise} \end{cases}$$

$t_{fb} = 250 \text{ (mm)}$

$t_{fb} := 300 \text{ (mm)}$

(Enlarge so the thicknes of the
top flange can be reduced)

Crane Girder Design
Page: 5

Crane Girder Top Flange Thickness:

(1) Thickness governed by statistical limits:

$$11.3 \leq \frac{t_{fb}}{t_{ft}} \leq 22$$

$$t_{ft_{prelim1}} := \frac{t_{fb}}{16.5} \quad (\text{Average from dimensional ratios}) \quad t_{ft_{prelim1}} = 18.182 \quad (\text{mm})$$

(2) Thickness governed by flange classification criteria - class 3 flange:

SABS 0162:1993,
Table 1

$$WTR_{Flange} := 200 \quad (\text{Width to thickness ratio}) \quad WTR_{Flange} = 200$$

$$t_{ft_{prelim2}} := \frac{(t_{fb} \cdot \sqrt{F_y})}{2 \cdot WTR_{Flange}} \quad t_{ft_{prelim2}} = 12.990 \quad (\text{mm})$$

(3) Thickness governed by serviceability criteria - deflection:

SABS 0162:1993
Appendix I

$$\Delta_{Limh} := 600 \quad (\text{Deflection Limit}) \quad \Delta_{Limh} = 600$$

(3.1) Misalignment:

$$Wheelbase_m := 900 \quad (\text{Distance Between Wheels}) \quad Wheelbase_m = 900 \quad (\text{mm})$$

$$a := \frac{L_{CG}}{2} - \frac{Wheelbase_m}{2} \quad a = 1800 \quad (\text{mm})$$

SASCH Table 5.7

$$\Delta_{H1} := P_{t2s} \cdot L_{CG}^2 \cdot \frac{a}{24 \cdot E} \cdot \left[3 - 4 \cdot \left(\frac{a}{L_{CG}} \right)^2 \right]$$

$$\Delta_{H1} = 352260442 \quad (\text{mm}^5)$$

$$\Delta_{MaxH} := \frac{L_{CG}}{\Delta_{Limh}} \quad \Delta_{MaxH} = 7.500 \quad (\text{mm})$$

$$I_{H1_{prelim}} := \frac{\Delta_{H1}}{\Delta_{MaxH}} \quad I_{H1_{prelim}} = 46968059 \quad (\text{mm}^4)$$

$$t_{ft_{prelim3}} := \frac{I_{H1_{prelim}} \cdot 12}{t_{fb}^3} \quad t_{ft_{prelim3}} = 20.875 \quad (\text{mm})$$

(3.2) Skewing:

$Wheelbase_s := Wheelbase_m$ $Wheelbase_s = 900 \quad (mm)$

$a_3 := \frac{L_{CG}}{2} \quad b_3 := L_{CG} - a_3$

SASCH Table 5.7 $\Delta_{H2} := \frac{P_{t3s} \cdot a_3^2 \cdot b_3^2}{3 \cdot E \cdot L_{CG}}$ $\Delta_{H2} = 186578624 \quad (mm^5)$

$I_{H2Prelim} := \frac{\Delta_{H2}}{\Delta_{MaxH}}$ $I_{H2Prelim} = 24877150 \quad (mm^4)$

$tft_{prelim4} := \frac{I_{H2Prelim} \cdot 12}{tfb^3}$ $tft_{prelim4} = 11.057 \quad (mm)$

$tft_{prelim5} := \begin{cases} tft_{prelim1} & \text{if } tft_{prelim1} \geq tft_{prelim2} \wedge tft_{prelim1} \geq tft_{prelim3} \wedge tft_{prelim1} \geq tft_{prelim4} \\ tft_{prelim2} & \text{if } tft_{prelim2} \geq tft_{prelim1} \wedge tft_{prelim2} \geq tft_{prelim3} \wedge tft_{prelim2} \geq tft_{prelim4} \\ tft_{prelim3} & \text{if } tft_{prelim3} \geq tft_{prelim1} \wedge tft_{prelim3} \geq tft_{prelim2} \wedge tft_{prelim3} \geq tft_{prelim4} \\ tft_{prelim4} & \text{otherwise} \end{cases}$

$tft_{prelim5} = 20.875 \quad (mm)$

$tft := \begin{cases} 14 & \text{if } tft_{prelim5} \leq 14 \\ 16 & \text{if } 14 < tft_{prelim5} \leq 16 \\ 18 & \text{if } 16 < tft_{prelim5} \leq 18 \\ 20 & \text{otherwise} \end{cases}$ $tft = 20 \quad (mm)$

Crane Girder Design
Page: 7

Crane Girder Bottom Flange Width and Thickness

(1) Min Bottom Flange Width

$$bfb_{minPrelim} := 150$$

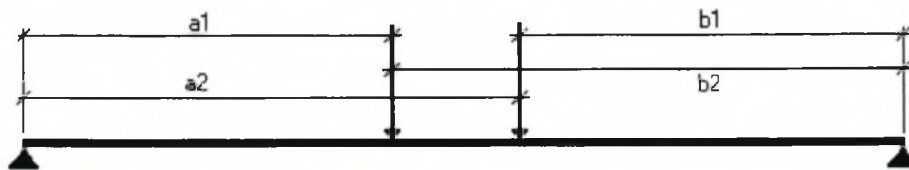
Choose 150 because: Estimate support width of crane column, bfb greater or equal to half of top flange width. $bfb_{minPrelim} = 150$ (mm)

(2) Use Flange classification criteria (class 3 flange) with web stabilisation requirements to determine initial (preliminary) flange properties:

Determine load case that provides worst case of concentrated force:

(2.1) Determine equivalent force for case: Misalignment with two vertical wheel forces on the span.

Maximum Vertical Moment:



$$a_1 := \frac{L_{CG}}{2} - \frac{Wheelbase_m}{2}$$

$$b_1 := a_1$$

$$a_2 := \frac{L_{CG}}{2} + \frac{Wheelbase_m}{2}$$

$$b_2 := a_2$$

$$R_L := \frac{V_{ui}(b_2 + b_1)}{L_{CG}}$$

$$R_L = 100000 \quad (N)$$

$$M_1 := R_L \cdot a_1$$

$$M_1 = 180000000 \quad (N \cdot mm)$$

$$M_2 := R_L \cdot a_2 - V_{ui}(a_2 - a_1)$$

$$M_2 = 180000000 \quad (N \cdot mm)$$

$$M_{Max} := \begin{cases} M_1 & \text{if } M_1 \geq M_2 \\ M_2 & \text{otherwise} \end{cases}$$

$$M_{Max} = 180000000 \quad (N \cdot mm)$$

$$P_{VEquivalent} := \frac{4 \cdot M_{Max}}{L_{CG}}$$

$$P_{VEquivalent} = 160000 \quad (N)$$

(Rosswell formula for single load P.)

Crane Girder Design
Page: 8

$OP_{FABRatio} := 1250$

Span to out-of-plane straitness ratio for
girder bottom flange

$OP_{FABRatio} = 1250$

$\Delta_o := \frac{L_{CG}}{OP_{FABRatio}}$

$\Delta_o = 3.600 \quad (\text{mm})$

SABS 0160: 1989
Tabel I.1

$SHDL := 600$

Span to horizontal deflection limit

$SHDL = 600$

$\Delta_{BotFlangeLim} := \frac{L_{CG}}{SHDL}$

$\Delta_{BotFlangeLim} = 7.5 \quad (\text{mm})$

$5.89 < SGDR < 31.58$

Span to depth Ratio: From Dimensional Ratios

$SGDR_{Avr} := 10.31$

Span to depth Ratio Average:
From Dimensional Ratios

$SGDR_{Avr} = 10.31$

$MinGirderD := \frac{L_{CG}}{SGDR_{Avr}}$

$MinGirderD = 436.469 \quad (\text{mm})$

Requiered stiffness of bottom flange:

$\beta_{BotFlange} := \frac{P_{VEquivalent}}{MinGirderD} \left(1 + \frac{\Delta_o}{\Delta_{BotFlangeLim}} \right)$

$\beta_{BotFlange} = 542.535 \quad \left(\frac{N}{mm} \right)$

$I_{BotFlangeReq} := \frac{(\beta_{BotFlange} \cdot L_{CG}^3)}{48 \cdot E}$

$I_{BotFlangeReq} = 5061272.73 \quad (\text{mm}^4)$

SABS 0162:1993
Table 1

$WTR_{Flange} = 200$

Width to thickness ratio

$WTR_{Flange} = 200$

$bfb_{prelim1} := \sqrt[4]{\frac{(24 \cdot WTR_{Flange} \cdot I_{BotFlangeReq})}{\sqrt{F_y}}}$

$bfb_{prelim1} = 193.524 \quad (\text{mm})$

$bfb_{prelim2} := \begin{cases} bfb_{minPrelim} & \text{if } bfb_{minPrelim} \geq bfb_{prelim1} \\ bfb_{prelim1} & \text{otherwise} \end{cases}$

$bfb_{prelim2} = 193.524 \quad (\text{mm})$

$bfb := \begin{cases} 100 & \text{if } bfb_{prelim2} \leq 100 \\ 150 & \text{if } 100 < bfb_{prelim2} \leq 150 \\ 200 & \text{if } 150 < bfb_{prelim2} \leq 200 \\ 250 & \text{if } 200 < bfb_{prelim2} \leq 250 \\ 300 & \text{if } 250 < bfb_{prelim2} \leq 300 \\ 350 & \text{otherwise} \end{cases}$

$bfb = 200 \quad (\text{mm})$

Crane Girder Design
Page: 9

$$bft_{prelim1} := \frac{bfb \cdot \sqrt{F_y}}{2 \cdot WTR_{Flange}}$$

$bft_{prelim1} = 8.66 \quad (mm)$

12.5 < WTR_{BotFlange} < 35.7

Width to Thickness Ratio of Bottom
Flange: From Stats

WTR_{BotFlangeAve} := 35.7

Span to depth ratio maksimum for
slander beam: From Dimensional Ratios

WTR_{BotFlangeAve} = 35.7

$$bft_{prelim2} := \frac{bfb}{WTR_{BotFlangeAve}}$$

$bft_{prelim2} = 5.602 \quad (mm)$

$$bft_{prelim3} := \begin{cases} bft_{prelim1} & \text{if } bft_{prelim1} \geq bft_{prelim2} \\ bft_{prelim2} & \text{otherwise} \end{cases}$$

$bft_{prelim3} = 8.66 \quad (mm)$

$$bft := \begin{cases} 5 & \text{if } bft_{prelim3} \leq 5 \\ 6 & \text{if } 5 < bft_{prelim3} \leq 6 \\ 8 & \text{if } 6 < bft_{prelim3} \leq 8 \\ 10 & \text{if } 8 < bft_{prelim3} \leq 10 \\ 12 & \text{if } 10 < bft_{prelim3} \leq 12 \\ 14 & \text{if } 12 < bft_{prelim3} \leq 14 \\ 16 & \text{if } 14 < bft_{prelim3} \leq 16 \\ 20 & \text{otherwise} \end{cases}$$

$bft = 10 \quad (mm)$

Crane Girder Web Depth:

Determine the depth of the web from a calculation of the vertical deflection considering only the flanges when calculating the second moment of area.

$$\Delta_{vi} := \frac{V_{ui}}{P_{t2s}} \cdot \Delta_{H1} \quad \Delta_{vi} = 1761302211.3 \text{ (mm}^5\text{)}$$

SABS 0162:1993
Appendix I

$$\Delta_{LimV} := 600$$

Crane capacity is < 22.5 Tonne

$$\Delta_{LimV} = 600$$

$$\Delta_{MaxV} := \frac{L_{CG}}{\Delta_{LimV}}$$

$$\Delta_{MaxV} = 7.500 \text{ (mm)}$$

$$I_{VPrelimReq} := \frac{\Delta_{vi}}{\Delta_{MaxV}}$$

$$I_{VPrelimReq} = 234840294.8 \text{ (mm}^4\text{)}$$

$$h_{wprelim1} := \text{MinGirderD}$$

$$h_{wprelim1} = 436.47 \text{ (mm)}$$

$$h_{prelim1} := tft + h_{wprelim1} + bft$$

$$h_{prelim1} = 466.47 \text{ (mm)}$$

$$Y_{NA1} := tfb \cdot \frac{tft^2}{2} + bfb \cdot bft \cdot \left(tft + h_{wprelim1} + \frac{bft}{2} \right)$$

(Without web and rail)

$$Y_{NA2} := tfb \cdot tft + bfb + bft$$

$$Y_{NA} := \frac{Y_{NA1}}{Y_{NA2}}$$

$$Y_{NA} = 158.283 \text{ (mm)}$$

$$I_{V2Prelim} := \frac{(tfb \cdot tft^3)}{12} + \frac{(bfb \cdot bft^3)}{12}$$

$$I_{V2Prelim} = 216666.67$$

$$I_{V3Prelim} := tfb \cdot tft \cdot \left(Y_{NA} - \frac{tft}{2} \right)^2$$

$$I_{V3Prelim} = 131927508.1$$

$$I_{V4Prelim} := bfb \cdot bft \cdot \left(tft + h_{wprelim1} - Y_{NA} + \frac{bft}{2} \right)^2$$

$$I_{V4Prelim} = 183843757.5$$

$$I_{V5Prelim} := I_{V2Prelim} + I_{V3Prelim} + I_{V4Prelim}$$

$$I_{V5Prelim} = 315987932.27 \text{ (mm}^4\text{)}$$

$$I_{VPrelim} := \begin{cases} \text{"OK"} & \text{if } I_{V5Prelim} \geq I_{VPrelimReq} \\ \text{"Fail"} & \text{otherwise} \end{cases}$$

$$I_{VPrelim} = \text{"OK"}$$

Crane Girder Design
Page: 11

$$h_{wprelim2} := \begin{cases} h_{wprelim1} & \text{if } h_{wprelim1} \geq \text{MinGirderD} \\ \text{MinGirderD} & \text{otherwise} \end{cases} \quad h_{wprelim2} = 436.469 \quad (\text{mm})$$

$$h_w := \begin{cases} 200 & \text{if } h_{wprelim2} \leq 200 \\ 250 & \text{if } 200 < h_{wprelim2} \leq 250 \\ 300 & \text{if } 250 < h_{wprelim2} \leq 300 \\ 350 & \text{if } 300 < h_{wprelim2} \leq 350 \\ 400 & \text{if } 350 < h_{wprelim2} \leq 400 \\ 450 & \text{if } 400 < h_{wprelim2} \leq 450 \\ 500 & \text{otherwise} \end{cases} \quad h_w = 450 \quad (\text{mm})$$

$$h := h_w + t_{ft} + b_{ft} \quad h = 480 \quad (\text{mm})$$

Crane Girder Web Thickness

(1) Web Slenderness Limit:

SABS 0160:1993
Tabel 1

$$\begin{aligned} WTR_{Web} &:= 1900 && \text{Width to Thickness ratio: Web} && WTR_{Web} = 1900 \\ t_{wprelim1} &:= \frac{(h_w \cdot \sqrt{F_y})}{WTR_{Web}} && && t_{wprelim1} = 4.102 \quad (\text{mm}) \end{aligned}$$

(2) Web Stability under Vertical Crane Wheel Forces

$$\begin{aligned} \text{SumNumWheels} &:= 2 && \text{Number of wheels between stiffeners} && \text{SumNumWheels} = 2 \\ V_{TotalStatic} &:= \text{SumNumWheels} \cdot V_{ul} && && V_{TotalStatic} = 200000 \quad (\text{N}) \\ S &:= L_{CG} && && S = 4500 \quad (\text{mm}) \\ S_S &:= \begin{cases} h_w & \text{if } h_w \leq S \\ S & \text{otherwise} \end{cases} && && S_S = 450 \quad (\text{mm}) \\ F_{WebResMin} &:= V_{TotalStatic} && && F_{WebResMin} = 200000 \quad (\text{N}) \end{aligned}$$

SABS 0162:1984

$$t_{wprelim2} := \sqrt[3]{\frac{F_{WebResMin}}{\frac{S_S E}{1.5} + 1 + \frac{2}{\left(\frac{S}{h_w}\right)^2} + \frac{1}{h_w^2}}} \quad t_{wprelim2} = 8.664 \quad (\text{mm})$$

$$t_w := \begin{cases} t_{wprelim1} & \text{if } t_{wprelim1} \geq t_{wprelim2} \\ t_{wprelim2} & \text{otherwise} \end{cases} \quad t_w = 8.664 \quad (\text{mm})$$

$$t_w := 10 \quad (\text{mm})$$

Crane Girder Design Properties:

$$A_{y1} := \frac{t_{fb} \cdot t_{ft}^2}{2} + b_{fb} \cdot b_{ft} \cdot \left(h - \frac{b_{ft}}{2} \right)$$

$$A_{y1} = 1010000 \quad (\text{mm}^3)$$

$$A_{y2} := h_w \cdot t_w \cdot \left(t_{ft} + \frac{h_w}{2} \right)$$

$$A_{y2} = 1102500 \quad (\text{mm}^3)$$

$$A := t_{ft} \cdot t_{fb} + h_w \cdot t_w + b_{ft} \cdot b_{fb}$$

$$A = 12500 \quad (\text{mm}^2)$$

$$Y_{NA} := \frac{(A_{y1} + A_{y2})}{A}$$

$$Y_{NA} = 169.000 \quad (\text{mm})$$

$$I_{xx1} := \frac{(t_{fb} \cdot t_{ft}^3)}{12} + t_{fb} \cdot t_{ft} \cdot \left(Y_{NA} - \frac{t_{ft}}{2} \right)^2$$

$$I_{xx2} := \frac{(b_{fb} \cdot b_{ft}^3)}{12} + b_{fb} \cdot b_{ft} \cdot \left(h - Y_{NA} + \frac{b_{ft}}{2} \right)^2$$

$$I_{xx3} := \frac{(t_w \cdot h_w^3)}{12} + b_{fb} \cdot h_w \cdot \left(t_{ft} - Y_{NA} + \frac{h_w}{2} \right)^2$$

$$I_{xx} := I_{xx1} + I_{xx2} + I_{xx3}$$

$$I_{xx} = 434392166.67 \quad (\text{mm}^4)$$

$$Z_{x1} := \frac{I_{xx}}{Y_{NA}}$$

$$Z_{x1} = 2570367.85 \quad (\text{mm}^3)$$

$$Z_{xb} := \frac{I_{xx}}{(h - Y_{NA})}$$

$$Z_{xb} = 1396759.38 \quad (\text{mm}^3)$$

Crane Girder Design
Page: 13

$$I_{yt} := \frac{(tft \cdot tfb^3)}{12} \quad I_{yt} = 45000000 \quad (\text{mm}^4)$$

$$I_{yb} := \frac{(bft \cdot bfb^3)}{12} \quad I_{yb} = 6666666.67 \quad (\text{mm}^4)$$

$$Z_{yt} := \frac{I_{yt}}{\left(\frac{tft}{2}\right)} \quad Z_{yt} = 300000 \quad (\text{mm}^3)$$

$$Z_{yb} := \frac{I_{yb}}{\left(\frac{bfb}{2}\right)} \quad Z_{yb} = 66666.67 \quad (\text{mm}^3)$$

$$I_y := I_{yt} + I_{yb} \quad I_y = 51666666.67 \quad (\text{mm}^4)$$

Structural Steel Design
Par 4.4.4.9

$$\beta := \frac{1}{1 + \left(\frac{tft}{bfb}\right)^3 \cdot \left(\frac{tft}{bft}\right)} \quad \beta = 0.129$$

$$Y_o := \left[Y_{NA} - tft - \beta \cdot \left(h - \frac{tft}{2} - \frac{bft}{2} \right) \right] \quad Y_o = -89.000 \quad (\text{mm})$$

$$J := \frac{1}{3} \cdot (tft \cdot tft^3 + h_w \cdot t_w^3 + bft \cdot bft^3) \quad J = 10166666.67 \quad (\text{mm}^4)$$

$$C_w := \frac{\left(h - \frac{tft}{2} - \frac{bft}{2} \right)^2 \cdot tft^3 \cdot tft \cdot \beta}{12} \quad C_w = 1.256E+012 \quad (\text{mm}^6)$$

Crane Girder Design
Page: 14

Weight of Crane Girder:

$$W_{CGwpm} := \frac{\gamma_{300WA}}{10^9} \cdot A$$

$$W_{CGwpm} = 98E-003 \quad \left(\frac{\text{kg}}{\text{mm}} \right)$$

Dead Load For Design Purposes:

$$W_{Rail10} := \frac{30}{10^3}$$

$$W_{Rail10} = 0.030 \quad \left(\frac{\text{kg}}{\text{mm}} \right)$$

$$b_{pad} := 63.5 \quad \text{Elastrometric Pad Width}$$

$$b_{pad} = 63.5 \quad (\text{mm})$$

$$W_{Pad} := \frac{1}{10^3}$$

$$W_{Pad} = 0.001 \quad \left(\frac{\text{kg}}{\text{mm}} \right)$$

$$g := 9.81$$

$$g = 9.81 \quad \left(\frac{\text{m}}{\text{s}^2} \right)$$

$$W_{CGservkg} := W_{Rail10} + W_{CGwpm} + W_{Pad}$$

$$W_{CGservkg} = 0.129 \quad \left(\frac{\text{kg}}{\text{mm}} \right)$$

$$W_{CGserv} := W_{CGservkg} \cdot g$$

$$W_{CGserv} = 1.267 \quad \left(\frac{\text{N}}{\text{mm}} \right)$$

$$W_{CGult} := DLF \cdot W_{CGserv}$$

$$W_{CGult} = 1.393 \quad \left(\frac{\text{N}}{\text{mm}} \right)$$

$$R_{CGserv} := W_{CGserv} \cdot \frac{L_{CG}}{2}$$

$$R_{CGserv} = 2850.11 \quad (\text{N})$$

$$R_{CGult} := W_{CGult} \cdot \frac{L_{CG}}{2}$$

$$R_{CGult} = 3135.12 \quad (\text{N})$$

Vertical Bending:

Case 1: Misalignment with crane end carriage wheelbase:

$$R_{vLultm} := \frac{\left(W_{CGult} \cdot \frac{L_{CG}^2}{2} \right) + V_{ui} \cdot (b_1 + b_2)}{L_{CG}} \quad R_{vLultm} = 103135.12 \quad (N)$$

$$M_{Lultm} := R_{vLultm} \cdot a_1 - W_{CGult} \cdot \frac{a_1^2}{2} \quad M_{Lultm} = 185641966.84 \quad (N \cdot mm)$$

$$M_{Rultm} := R_{vLultm} \cdot a_2 - \left(W_{CGult} \cdot \frac{a_2^2}{2} \right) - V_{ui} \cdot (a_2 - a_1) \quad M_{Rultm} = 188462950.27 \quad (N \cdot mm)$$

$$M_{Vultm} := \begin{cases} M_{Lultm} & \text{if } M_{Lultm} \leq M_{Rultm} \\ M_{Rultm} & \text{otherwise} \end{cases} \quad M_{Vultm} = 185641966.84 \quad (N \cdot mm)$$

$$F_{vTopultm} := \frac{M_{Vultm}}{Z_{xt}} \quad F_{vTopultm} = 72.224 \quad (MPa)$$

$$F_{vBotultm} := \frac{M_{Vultm}}{Z_{xb}} \quad F_{vBotultm} = 132.909 \quad (MPa)$$

Case 2: Screwing with crane end carriage Wheelbase:

$$R_{vLults} := \frac{W_{CGult} \cdot \frac{L_{CG}^2}{2} + V_{ui} \cdot b_3}{L_{CG}} \quad R_{vLults} = 53135.12 \quad (N)$$

$$M_{Lults} := R_{vLults} \cdot a_3 - W_{CGult} \cdot \frac{a_3^2}{2} \quad M_{Lults} = 116027013.06 \quad (N \cdot mm)$$

$$M_{Vults} := M_{Lults} \quad M_{Vults} = 116027013.06 \quad (N \cdot mm)$$

$$F_{vTopults} := \frac{M_{Vults}}{Z_{xt}} \quad F_{vTopults} = 45.140 \quad (N)$$

$$F_{vBotults} := \frac{M_{Vults}}{Z_{xb}} \quad F_{vBotults} = 83.069 \quad (N)$$

Transverse Bending:

$h_{Rail30} := 109.5$ $h_{Rail30} = 109.5 \quad (\text{mm})$

$h_{sc} := h_{Rail30} + t_{pad} + Y_{NA} + Y_o$ $h_{sc} = 196.5 \quad (\text{mm})$

$e_{Rail} := 0.5 \cdot t_w + 0.001 \cdot L_{CG}$ $e_{Rail} = 9.500 \quad (\text{mm})$

Case 1: Misalignment:

$H_m := P_{l2s}$ $H_m = 20000 \quad (\text{N})$

$V_m := V_{ui}$ $V_m = 100000 \quad (\text{N})$

Case 2: Skewing:

$H_s := P_{l3s}$ $H_s = 20000 \quad (\text{N})$

$V_s := V_{ui}$ $V_s = 100000 \quad (\text{N})$

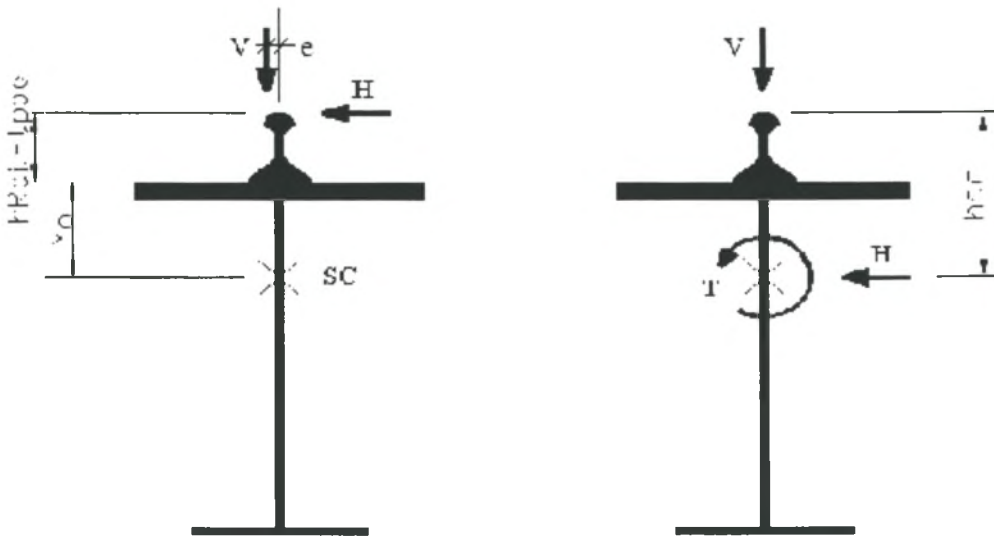
Resultant Torsional Moments:

$T_{mH} := H_m \cdot h_{sc}$ $T_{mH} = 3930000 \quad (\text{kN} \cdot \text{mm})$

$T_{mV} := V_m \cdot e_{Rail}$ $T_{mV} = 950000 \quad (\text{N} \cdot \text{mm})$

$T_{sH} := H_s \cdot h_{sc}$ $T_{sH} = 3930000 \quad (\text{N} \cdot \text{mm})$

$T_{sV} := V_s \cdot e_{Rail}$ $T_{sV} = 950000 \quad (\text{N} \cdot \text{mm})$



Calculate horizontal deflection, flange forces, moments, and stresses due to the following applied forces and force effects at crane wheel positions:

- (1) Out-of-straightness tolerance due to fabrication practices.
- (2) Transverse displacement due to transverse wheel forces at rail head level.
- (3) Transverse deflection due to the force effect: torsion about the shear centre caused by the transverse wheel forces.
- (4) Transverse deflection due to the force effect torsion due to vertical wheel forces offset by misalignment of the crane rail.
- (5) Transverse deflection due to the force effect: stabilisation forces for the web, which acts as a column under the vertical wheel forces.

Note:

- (a) Transverse thrusts / forces are resolved as equivalent horizontal forces and torsional moments about the centroid of the girder section.
- (b) The equivalent horizontal force at the centroid of the girder section is resolved into equivalent horizontal forces at the top and bottom flange (by taking moments about the centroid of the top and bottom flange).
- (c) Torsional moments are resolved as equal horizontal force couples. The lever arm is the distance between the top and bottom flange centroids.
- (d) Horizontal flange forces resolved from torsional moments are adjusted to obtain the warping torsion component, which contributes to the longitudinal stresses and deflections.

(1) Transverse out-of-plane straightness of the girder:

$$\Delta_o = 3.6 \quad \text{(Transverse out-of-plane straightness of the bottom flange:)} \quad \Delta_o = 3.6 \quad (\text{mm})$$

(2) Transverse displacements due to transverse wheel forces applied at rail head level:

$$h_{ff} := h - \frac{t_{ft}}{2} - \frac{b_{ft}}{2} \quad h_{ff} = 465 \quad (\text{mm})$$

$$h_{sctf} := Y_{NA} + Y_o - t_{ft} \quad h_{sctf} = 60 \quad (\text{mm})$$

$$h_{scbf} := h - \frac{b_{ft}}{2} - Y_{NA} + |Y_o| \quad h_{scbf} = 395.000 \quad (\text{mm})$$

Take moments about the centerline of the bottom flange:

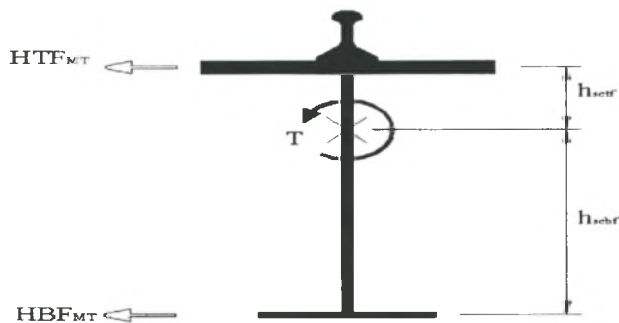
$$HTF_{mt} := H_m \cdot \frac{h_{scbf}}{h_{ff}} \quad HTF_{mt} = 16989.25 \quad (\text{N})$$

$$HTF_{st} := H_s \cdot \frac{h_{scbf}}{h_{ff}} \quad HTF_{st} = 16989.25 \quad (\text{N})$$

Take moments about the centerline of the top flange:

$$HBF_{mt} := H_m \cdot \frac{h_{sctf}}{h_{ff}} \quad HBF_{mt} = 2580.65 \quad (\text{N})$$

$$HBF_{st} := H_s \cdot \frac{h_{sctf}}{h_{ff}} \quad HBF_{st} = 2580.65 \quad (\text{N})$$



Top and bottom flange deflection:

$$\delta TF_{mt} := \left[\frac{L_{CG}^2 \cdot a_1}{24} \left[3 - 4 \cdot \left(\frac{a_1}{L_{CG}} \right)^2 \right] \right] \cdot \left(\frac{HTF_{mt}}{E \cdot I_{yt}} \right)$$

$$\delta TF_{mt} = 6.650 \quad (\text{mm})$$

$$\delta BF_{mt} := \left[\frac{L_{CG}^2 \cdot a_1}{24} \left[3 - 4 \cdot \left(\frac{a_1}{L_{CG}} \right)^2 \right] \right] \cdot \left(\frac{HBF_{mt}}{E \cdot I_{yb}} \right)$$

$$\delta BF_{mt} = 6.818 \quad (\text{mm})$$

$$\delta TF_{st} := \left(\frac{a_3^2 \cdot b_3^2}{3 \cdot L_{CG}} \right) \cdot \left(\frac{HTF_{st}}{E \cdot I_{yt}} \right)$$

$$\delta TF_{st} = 3.522 \quad (\text{mm})$$

$$\delta BF_{st} := \left(\frac{a_3^2 \cdot b_3^2}{3 \cdot L_{CG}} \right) \cdot \left(\frac{HBF_{st}}{E \cdot I_{yb}} \right)$$

$$\delta BF_{st} = 3.611 \quad (\text{mm})$$

(3) &(4) Transverse Deflection due to the force effect: Torsion about the shear centre caused by the transverse wheel forces and transverse deflection due to the force effect: Torsion due to vertical wheel forces offset by misalignment of the crane rail.

Case 1: Misalignment

$$\alpha_{m1} := \begin{cases} \frac{a_1}{L_{CG}} & \text{if } \frac{a_1}{L_{CG}} < 0.5 \\ \left(1 - \frac{a_1}{L_{CG}}\right) & \text{otherwise} \end{cases} \quad \alpha_{m1} = 0.400$$

$$\alpha_{m2} := \begin{cases} \frac{a_2}{L_{CG}} & \text{if } \frac{a_2}{L_{CG}} < 0.5 \\ \left(1 - \frac{a_2}{L_{CG}}\right) & \text{otherwise} \end{cases} \quad \alpha_{m2} = 0.400$$

$$\alpha_m := \begin{cases} \alpha_{m1} & \text{if } \alpha_{m1} \leq \alpha_{m2} \\ \alpha_{m2} & \text{otherwise} \end{cases} \quad \alpha_m = 0.400$$

$$\lambda := \sqrt{\frac{G \cdot J}{E \cdot C_w}} \quad \lambda = 0.000558$$

$$\lambda L := \lambda \cdot L_{CG} \quad \lambda L = 2.511 \quad (\text{m})$$

Salmon & Johnson
Table 8.6.1

$$\beta_m := 0.7$$

With α_m and λL known

$$\beta_m = 0.70$$

Case 2: Skewing

$$\alpha_s := \frac{a_3}{L_{CG}} \quad \alpha_s = 0.500$$

Salmon & Johnson
Table 8.6.2

$$\beta_s := 0.88$$

With α_s and λL known

$$\beta_s = 0.88$$

Equivalent Flange Forces And Deflections:

$$HTF_{mhft} := \frac{T_{mH}}{h_{ff}} \cdot \beta_m \quad HTF_{mhft} = 5916.13 \quad (N)$$

$$HTF_{shft} := \frac{T_{sH}}{h_{ff}} \cdot \beta_s \quad HTF_{shft} = 7437.42 \quad (N)$$

$$HTF_{mvft} := \frac{T_{mV}}{h_{ff}} \cdot \beta_m \quad HTF_{mvft} = 1430.11 \quad (N)$$

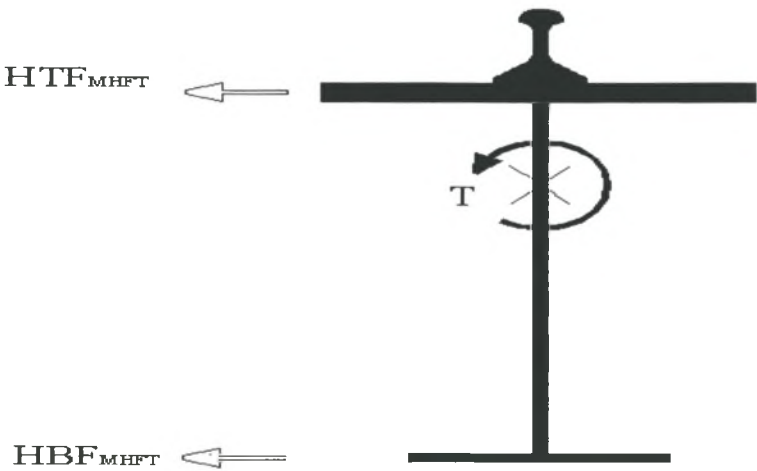
$$HTF_{svft} := \frac{T_{sV}}{h_{ff}} \cdot \beta_s \quad HTF_{svft} = 1797.85 \quad (N)$$

$$HBF_{mhft} := -HTF_{mhft} \quad HBF_{mhft} = -5916.13 \quad (N)$$

$$HBF_{shft} := -HTF_{shft} \quad HBF_{shft} = -7437.42 \quad (N)$$

$$HBF_{mvft} := -HTF_{mvft} \quad HBF_{mvft} = -1430.11 \quad (N)$$

$$HBF_{svft} := -HTF_{svft} \quad HBF_{svft} = -1797.85 \quad (N)$$



Top and Bottom Flange Deflection:

$$\delta TF_{mhft} := \left[\frac{L_{CG}^2 \cdot a_1}{24} \left[3 - 4 \cdot \left(\frac{a_1}{L_{CG}} \right)^2 \right] \right] \cdot \left(\frac{HTF_{mhft}}{E \cdot I_{y1}} \right)$$

$$\delta TF_{mhft} = 2.316 \quad (\text{mm})$$

$$\delta BF_{mhft} := \left[\frac{L_{CG}^2 \cdot a_1}{24} \left[3 - 4 \cdot \left(\frac{a_1}{L_{CG}} \right)^2 \right] \right] \cdot \left(\frac{HBF_{mhft}}{E \cdot I_{yb}} \right)$$

$$\delta BF_{mhft} = -15.630 \quad (\text{mm})$$

$$\delta TF_{mvft} := \left[\frac{L_{CG}^2 \cdot a_1}{24} \left[3 - 4 \cdot \left(\frac{a_1}{L_{CG}} \right)^2 \right] \right] \cdot \left(\frac{HTF_{mvft}}{E \cdot I_{y1}} \right)$$

$$\delta TF_{mvft} = 0.560 \quad (\text{mm})$$

$$\delta BF_{mvft} := \left[\frac{L_{CG}^2 \cdot a_1}{24} \left[3 - 4 \cdot \left(\frac{a_1}{L_{CG}} \right)^2 \right] \right] \cdot \left(\frac{HBF_{mvft}}{E \cdot I_{yb}} \right)$$

$$\delta BF_{mvft} = -3.778 \quad (\text{mm})$$

$$\delta TF_{shft} := \left(\frac{a_3^2 \cdot b_3^2}{3 \cdot L_{CG}} \right) \cdot \left(\frac{HTF_{shft}}{E \cdot I_{y1}} \right)$$

$$\delta TF_{shft} = 1.542 \quad (\text{mm})$$

$$\delta BF_{shft} := \left(\frac{a_3^2 \cdot b_3^2}{3 \cdot L_{CG}} \right) \cdot \left(\frac{HBF_{shft}}{E \cdot I_{yb}} \right)$$

$$\delta BF_{shft} = -10.407 \quad (\text{mm})$$

$$\delta TF_{svft} := \left(\frac{a_3^2 \cdot b_3^2}{3 \cdot L_{CG}} \right) \cdot \left(\frac{HTF_{svft}}{E \cdot I_{y1}} \right)$$

$$\delta TF_{svft} = 1.542 \quad (\text{mm})$$

$$\delta BF_{svft} := \left(\frac{a_3^2 \cdot b_3^2}{3 \cdot L_{CG}} \right) \cdot \left(\frac{HBF_{svft}}{E \cdot I_{yb}} \right)$$

$$\delta BF_{svft} = -2.516 \quad (\text{mm})$$

(5) Transverse deflection due to the force effect: Stabilisation forces for the web, which acts as a column under the vertical wheel forces.

Assume stabilisation flange force:

$$HTF_{mwebst} := 1000$$

$$HTF_{mwebst} = 1000 \quad (N)$$

$$HBF_{mwebst} := -HTF_{mwebst}$$

$$HBF_{mwebst} = -1000 \quad (N)$$

$$HTF_{swebst} := 1000$$

$$HTF_{swebst} = 1000 \quad (N)$$

$$HBF_{swebst} := -HTF_{swebst}$$

$$HBF_{swebst} = -1000 \quad (N)$$

$$\delta TF_{mwebst} := \left[\frac{L_{CG}^2 \cdot a_1}{24} \left[3 - 4 \cdot \left(\frac{a_1}{L_{CG}} \right)^2 \right] \right] \left(\frac{HTF_{mwebst}}{E \cdot I_{yt}} \right)$$

$$\delta TF_{mwebst} = 0.391 \quad (mm)$$

$$\delta BF_{mwebst} := \left[\frac{L_{CG}^2 \cdot a_1}{24} \left[3 - 4 \cdot \left(\frac{a_1}{L_{CG}} \right)^2 \right] \right] \left(\frac{HBF_{mwebst}}{E \cdot I_{yb}} \right)$$

$$\delta BF_{mwebst} = -2.642 \quad (mm)$$

$$\delta TF_{swebst} := \left(\frac{a_3^2 \cdot b_3^2}{3 \cdot L_{CG}} \right) \left(\frac{HTF_{swebst}}{E \cdot I_{yt}} \right)$$

$$\delta TF_{swebst} = 0.207 \quad (mm)$$

$$\delta BF_{swebst} := \left(\frac{a_3^2 \cdot b_3^2}{3 \cdot L_{CG}} \right) \left(\frac{HBF_{swebst}}{E \cdot I_{yb}} \right)$$

$$\delta BF_{swebst} = -1.399 \quad (mm)$$

Perform Iteration Process to determine final value F_{wt} and Horizontal Flange Deflection.

Iteration 1:

$$\Delta_{TopFlangeM} := \delta TF_{mt} + \delta TF_{mhft} + \delta TF_{mvft} + \delta TF_{mwebst} \quad \Delta_{TopFlangeM} = 9.916 \quad (\text{mm})$$

$$\Delta_{BotFlangeM} := \delta BF_{mt} + \delta BF_{mhft} + \delta BF_{mvft} + \delta BF_{mwebst} \quad \Delta_{BotFlangeM} = -15.232 \quad (\text{mm})$$

$$\Delta_{mTilt} := |\Delta_{TopFlangeM}| + |\Delta_{BotFlangeM}| + \Delta_o \quad \Delta_{mTilt} = 28.749 \quad (\text{mm})$$

$$HTF_{mwebst} := \frac{V_m \cdot \Delta_{mTilt} \cdot \beta_m}{h_{ff}} \quad HTF_{mwebst} = 4327.77 \quad (\text{N})$$

$$HBF_{mwebst} := -HTF_{mwebst} \quad HBF_{mwebst} = -4327.77 \quad (\text{N})$$

$$\Delta_{TopFlangeS} := \delta TF_{st} + \delta TF_{shft} + \delta TF_{svft} + \delta TF_{swebst} \quad \Delta_{TopFlangeS} = 5.644 \quad (\text{mm})$$

$$\Delta_{BotFlangeS} := \delta BF_{st} + \delta BF_{shft} + \delta BF_{svft} + \delta BF_{swebst} \quad \Delta_{BotFlangeS} = -10.711 \quad (\text{mm})$$

$$\Delta_{sTilt} := |\Delta_{TopFlangeS}| + |\Delta_{BotFlangeS}| + \Delta_o \quad \Delta_{sTilt} = 19.955 \quad (\text{mm})$$

$$HTF_{swebst} := \frac{V_s \cdot \Delta_{sTilt} \cdot \beta_s}{h_{ff}} \quad HTF_{swebst} = 3776.49 \quad (\text{N})$$

$$HBF_{swebst} := -HTF_{swebst} \quad HBF_{swebst} = -3776.49 \quad (\text{N})$$

Iteration 2:

$$\delta TF_{mwebst} := \left[\frac{L_{CG}^2 \cdot a_l}{24} \left[3 - 4 \cdot \left(\frac{a_l}{L_{CG}} \right)^2 \right] \right] \cdot \left(\frac{HTF_{mwebst}}{E \cdot I_{yt}} \right)$$

$$\delta TF_{mwebst} = 1.694 \quad (\text{mm})$$

$$\delta BF_{mwebst} := \left[\frac{L_{CG}^2 \cdot a_l}{24} \left[3 - 4 \cdot \left(\frac{a_l}{L_{CG}} \right)^2 \right] \right] \cdot \left(\frac{HBF_{mwebst}}{E \cdot I_{yb}} \right)$$

$$\delta BF_{mwebst} = -11.434 \quad (\text{mm})$$

$$\Delta_{TopFlangeM} := \delta TF_{mt} + \delta TF_{mhft} + \delta TF_{mvft} + \delta TF_{mwebst}$$

$$\Delta_{TopFlangeM} = 11.219 \quad (\text{mm})$$

$$\Delta_{BotFlangeM} := \delta BF_{mt} + \delta BF_{mhft} + \delta BF_{mvft} + \delta BF_{mwebst}$$

$$\Delta_{BotFlangeM} = -24.024 \quad (\text{mm})$$

$$\Delta_{mTilt} := |\Delta_{TopFlangeM}| + |\Delta_{BotFlangeM}| + \Delta_o$$

$$\Delta_{mTilt} = 38.843 \quad (\text{mm})$$

$$HTF_{mwebst} := \frac{V_m \cdot \Delta_{mTilt} \cdot \beta_m}{h_{ff}}$$

$$HTF_{mwebst} = 5847.34 \quad (\text{N})$$

$$HBF_{mwebst} := -HTF_{mwebst}$$

$$HBF_{mwebst} = -5847.34 \quad (\text{N})$$

$$\delta TF_{swebst} := \left(\frac{a_3^2 \cdot b_3^2}{3 \cdot L_{CG}} \right) \cdot \left(\frac{HTF_{swebst}}{E \cdot I_{yt}} \right)$$

$$\delta TF_{swebst} = 0.783 \quad (\text{mm})$$

$$\delta BF_{swebst} := \left(\frac{a_3^2 \cdot b_3^2}{3 \cdot L_{CG}} \right) \cdot \left(\frac{HBF_{swebst}}{E \cdot I_{yb}} \right)$$

$$\delta BF_{swebst} = -5.285 \quad (\text{mm})$$

$$\Delta_{TopFlangeS} := \delta TF_{st} + \delta TF_{shft} + \delta TF_{svft} + \delta TF_{swebst}$$

$$\Delta_{TopFlangeS} = 6.219 \quad (\text{mm})$$

$$\Delta_{BotFlangeS} := \delta BF_{st} + \delta BF_{shft} + \delta BF_{svft} + \delta BF_{swebst}$$

$$\Delta_{BotFlangeS} = -14.597 \quad (\text{mm})$$

$$\Delta_{sTilt} := |\Delta_{TopFlangeS}| + |\Delta_{BotFlangeS}| + \Delta_o$$

$$\Delta_{sTilt} = 24.416 \quad (\text{mm})$$

$$HTF_{swebst} := \frac{V_s \cdot \Delta_{sTilt} \cdot \beta_s}{h_{ff}}$$

$$HTF_{swebst} = 4620.69 \quad (\text{N})$$

$$HBF_{swebst} := -HTF_{swebst}$$

$$HBF_{swebst} = -4620.69 \quad (\text{N})$$

Crane Girder Design
Page: 26

Iteration 3:

$$\delta TF_{mwebst} := \left[\frac{L_{CG}^2 \cdot a_1}{24} \left[3 - 4 \cdot \left(\frac{a_1}{L_{CG}} \right)^2 \right] \right] \cdot \left(\frac{HTF_{mwebst}}{E \cdot I_{y1}} \right)$$

$$\delta TF_{mwebst} = 2.289 \quad (\text{mm})$$

$$\delta BF_{mwebst} := \left[\frac{L_{CG}^2 \cdot a_1}{24} \left[3 - 4 \cdot \left(\frac{a_1}{L_{CG}} \right)^2 \right] \right] \cdot \left(\frac{HBF_{mwebst}}{E \cdot I_{yb}} \right)$$

$$\delta BF_{mwebst} = -15.448 \quad (\text{mm})$$

$$\Delta_{TopFlangeM} := \delta TF_{mt} + \delta TF_{mhft} + \delta TF_{mvft} + \delta TF_{mwebst}$$

$$\Delta_{TopFlangeM} = 11.814 \quad (\text{mm})$$

$$\Delta_{BotFlangeM} := \delta BF_{mt} + \delta BF_{mhft} + \delta BF_{mvft} + \delta BF_{mwebst}$$

$$\Delta_{BotFlangeM} = -28.039 \quad (\text{mm})$$

$$\Delta_{mTilt} := |\Delta_{TopFlangeM}| + |\Delta_{BotFlangeM}| + \Delta_o$$

$$\Delta_{mTilt} = 43.452 \quad (\text{mm})$$

$$HTF_{mwebst} := \frac{V_m \cdot \Delta_{mTilt} \cdot \beta_m}{h_{ff}}$$

$$HTF_{mwebst} = 6541.23 \quad (\text{N})$$

$$HBF_{mwebst} := -HTF_{mwebst}$$

$$HBF_{mwebst} = -6541.23 \quad (\text{N})$$

$$\delta TF_{swebst} := \left(\frac{a_3^2 \cdot b_3^2}{3 \cdot L_{CG}} \right) \cdot \left(\frac{HTF_{swebst}}{E \cdot I_{y1}} \right)$$

$$\delta TF_{swebst} = 0.958 \quad (\text{mm})$$

$$\delta BF_{swebst} := \left(\frac{a_3^2 \cdot b_3^2}{3 \cdot L_{CG}} \right) \cdot \left(\frac{HBF_{swebst}}{E \cdot I_{yb}} \right)$$

$$\delta BF_{swebst} = -6.466 \quad (\text{mm})$$

$$\Delta_{TopFlangeS} := \delta TF_{st} + \delta TF_{shft} + \delta TF_{svft} + \delta TF_{swebst}$$

$$\Delta_{TopFlangeS} = 6.395 \quad (\text{mm})$$

$$\Delta_{BotFlangeS} := \delta BF_{st} + \delta BF_{shft} + \delta BF_{svft} + \delta BF_{swebst}$$

$$\Delta_{BotFlangeS} = -15.778 \quad (\text{mm})$$

$$\Delta_{sTilt} := |\Delta_{TopFlangeS}| + |\Delta_{BotFlangeS}| + \Delta_o$$

$$\Delta_{sTilt} = 25.773 \quad (\text{mm})$$

$$HTF_{swebst} := \frac{V_s \cdot \Delta_{sTilt} \cdot \beta_s}{h_{ff}}$$

$$HTF_{swebst} = 4877.38 \quad (\text{N})$$

$$HBF_{swebst} := -HTF_{swebst}$$

$$HBF_{swebst} = -4877.38 \quad (\text{N})$$

Crane Girder Design
Page: 27

Verify Girder Resistance to Buckling:

Trahair

$$\beta_x := 0.9 \cdot h_{ff} \cdot \left(2 \cdot \frac{I_{yt}}{I_y} - 1 \right) \cdot \left[1 - \left(\frac{I_y}{I_{xx}} \right)^2 \right]$$

$$\beta_x = 306.11 \quad (\text{mm})$$

$$K := 0.1$$

Effective Length Factor

$$K = 0.1$$

$$\beta_1 := \frac{\pi \cdot \beta_x}{2 \cdot K \cdot L_{CG}} \cdot \sqrt{\frac{E \cdot I_y}{G \cdot J}}$$

$$\beta_1 = 12.282$$

$$\beta_2 := \frac{\pi^2 \cdot E \cdot C_w}{(K \cdot L_{CG})^2 \cdot G \cdot J}$$

$$\beta_2 = 156.490$$

SABS 0162-1:1993
Par 13.6 a.

$$\omega_2 := 1$$

$$\omega_2 = 1$$

$$M_{cr} := \frac{\omega_2 \cdot \pi}{K \cdot L_{CG}} \cdot \sqrt{E \cdot I_y \cdot G \cdot J} \cdot \left(\beta_1 + \sqrt{1 + \beta_2 + \beta_1^2} \right)$$

$$M_{cr} = 190.564\text{E}+009 \quad (\text{N} \cdot \text{mm})$$

$$M_{\text{TopxxYield}} := F_y \cdot Z_{xt}$$

$$M_{\text{TopxxYield}} = 771.11\text{E}+006 \quad (\text{N} \cdot \text{mm})$$

$$\gamma := 0.67$$

$$\gamma = 0.67$$

$$\gamma M_y := 0.67 \cdot M_{\text{TopxxYield}}$$

$$\gamma M_y = 516.644\text{E}+006 \quad (\text{N} \cdot \text{mm})$$

$$\phi M_{rx\text{Top}} := \begin{cases} \left[1.15 \cdot \phi_b \cdot M_{\text{TopxxYield}} \cdot \left(1 - 0.28 \cdot \frac{M_{\text{TopxxYield}}}{M_{cr}} \right) \right] & \text{if } M_{cr} \geq \gamma M_y \\ \left(\phi_b \cdot M_{\text{TopxxYield}} \right) & \text{otherwise} \end{cases}$$

$$\phi M_{rx\text{Top}} = 797194963.7 \quad (\text{N} \cdot \text{mm})$$

$$M_{\text{BotxxYield}} := F_y \cdot Z_{xb}$$

$$M_{\text{BotxxYield}} = 419\text{E}+006 \quad (\text{N} \cdot \text{mm})$$

$$\phi M_{rx\text{Bot}} := \phi_b \cdot M_{\text{BotxxYield}}$$

$$\phi M_{rx\text{Top}} = 797194963.7 \quad (\text{N} \cdot \text{mm})$$

$$F_{rx\text{Top}} := \frac{\phi M_{rx\text{Top}}}{Z_{xt}}$$

$$F_{rx\text{Top}} = 310.15 \quad (\text{MPa})$$

$$F_{rx\text{Bot}} := \frac{\phi M_{rx\text{Bot}}}{Z_{xb}}$$

$$F_{rx\text{Bot}} = 270 \quad (\text{MPa})$$

Crane Girder Design
Page: 28

Combined Stresses:

Web Shear Strength:

Web Buckling:

$$R_{\text{ShearUltLeft}} := \frac{V_{ui} \cdot [L_{CG} + (L_{CG} - \text{Wheelbase}_m)]}{L_{CG}}$$

$$R_{\text{ShearUltLeft}} = 180000 \quad (\text{N})$$

$$V_{\text{ShearUltLeft}} := R_{\text{ShearUltLeft}}$$

$$V_{\text{ShearUltLeft}} = 180000 \quad (\text{N})$$

$$\text{HTD}_{\text{Actual}} := \frac{h_w}{t_w}$$

$$\text{HTD}_{\text{Actual}} = 45.000$$

$$\text{HTD}_{\text{Limit}} := \frac{1100}{F_y}$$

$$\text{HTD}_{\text{Limit}} = 3.667$$

$$S := \frac{S}{5}$$

$$S = 900 \quad (\text{mm})$$

$$k_v := \begin{cases} \left[4 + \frac{5.34}{\left(\frac{S}{h_w} \right)} \right] & \text{if } \frac{S}{h_w} \leq 1 \\ \left[5.34 + \frac{4}{\left(\frac{S}{h_w} \right)} \right] & \text{otherwise} \end{cases}$$

$$k_v = 7.340$$

$$f_{\text{cri}} := \frac{(290 \cdot \sqrt{F_y \cdot k_v})}{\text{HTD}_{\text{Actual}}}$$

$$f_{\text{cri}} = 302.409 \quad (\text{MPa})$$

$$F_{vu} := \begin{cases} (0.66 \cdot F_y) & \text{if } \text{HTD}_{\text{Actual}} \leq 440 \cdot \sqrt{\frac{k_v}{F_y}} \\ f_{\text{cri}} & \text{if } 440 \cdot \sqrt{\frac{k_v}{F_y}} < \text{HTD}_{\text{Actual}} \leq 500 \cdot \sqrt{\frac{k_v}{F_y}} \\ \left[f_{\text{cri}} + (0.5 \cdot F_y - 0.866 \cdot f_{\text{cri}}) \cdot \left[\frac{1}{\sqrt{1 + \left(\frac{S}{h_w} \right)^2}} \right] \right] & \text{if } 500 \cdot \sqrt{\frac{k_v}{F_y}} < \text{HTD}_{\text{Actual}} \leq 620 \cdot \sqrt{\frac{k_v}{F_y}} \end{cases}$$

$$F_{vu} = 198.000 \quad (\text{MPa})$$

$$\phi_v := 0.9$$

$$\phi_v = 0.9$$

$$A_v := h_w \cdot t_w$$

$$A_v = 4500 \quad (\text{mm}^2)$$

$$V_{\text{ShearUltRes}} := \phi_v \cdot F_{vu} \cdot h_w \cdot t_w$$

$$V_{\text{ShearUltRes}} = 801900 \quad (\text{N})$$

$$V_{\text{SBuckCheck}} := \begin{cases} \text{"OK"} & \text{if } V_{\text{ShearUltRes}} \geq V_{\text{ShearUltLeft}} \\ \text{"FAIL"} & \text{otherwise} \end{cases}$$

$$V_{\text{SBuckCheck}} = \text{"OK"}$$

SABS 0162-1:1993
Par. 13.4.11

Crane Girder Design
Page: 29

SABS 0162:1993
Parr. 15.9

Web Crippling:

Interior Loading Condition

$$N := (h_{\text{Rail30}} + t_{\text{pad}} + t_{\text{ft}}) \cdot 2$$

$$N = 273 \quad (\text{mm})$$

$$B_{\text{cr}} := 300 \cdot \phi_b \cdot t_w^2 \cdot \left[1 + 3 \cdot \left(\frac{N}{h_w} \right) \cdot \left(\frac{t_w}{t_{\text{ft}}} \right)^{1.5} \right] \cdot \sqrt{F_y \cdot \frac{t_{\text{ft}}}{t_w}}$$

$$B_{\text{cr}} = 1086927.11 \text{ (N)}$$

$$B_{\text{crCheck}} := \begin{cases} \text{"OK"} & \text{if } B_{\text{cr}} \geq V_{\text{ui}} \\ \text{"FAIL"} & \text{otherwise} \end{cases}$$

$$B_{\text{crCheck}} = \text{"OK"}$$

SABS 0162:1993
Parr. 15.9

Web Yielding:

$$A_{\text{wy}} := t_w \cdot N$$

$$A_{\text{wy}} = 2730 \quad (\text{mm}^2)$$

$$B_{\text{ry}} := 1.1 \cdot \phi_b \cdot F_y \cdot A_{\text{wy}}$$

$$B_{\text{ry}} = 810810 \quad (\text{N})$$

$$B_{\text{ryCheck}} := \begin{cases} \text{"OK"} & \text{if } B_{\text{ry}} \geq V_{\text{ui}} \\ \text{"FAIL"} & \text{otherwise} \end{cases}$$

$$B_{\text{ryCheck}} = \text{"OK"}$$

sabs 0162

Web Stability:

$$V_{\text{TotalUlt}} := \text{SumNumWheels} \cdot V_{\text{ui}}$$

Total sum of vertical wheel forces
between stiffeners

$$V_{\text{TotalUlt}} = 200000 \quad (\text{N})$$

$$S_s := \begin{cases} h_w & \text{if } h_w \leq S \\ S & \text{otherwise} \end{cases}$$

$$S_s = 450 \quad (\text{mm})$$

$$F_{\text{WebRes}} := \frac{(S_s \cdot t_w \cdot E)}{1.5} \cdot \left[1 + \frac{2}{\left(\frac{S}{h_w} \right)^2} \right] \cdot \left(\frac{t_w}{h_w} \right)^2$$

$$F_{\text{WebRes}} = 452222.22 \quad (\text{MPa})$$

$$\text{WebS} := \begin{cases} \text{"OK"} & \text{if } F_{\text{WebRes}} \geq V_{\text{TotalUlt}} \\ \text{"FAIL"} & \text{otherwise} \end{cases}$$

$$\text{WebS} = \text{"OK"}$$

Bearing Stiffeners at Girder Ends:**(1) Design Load Check:**

$$R_{\text{ShearUltLeft}} = 180000$$

Maximum Girder end Reaction

$$R_{\text{ShearUltLeft}} = 180000 \quad (\text{N})$$

$$t_{\text{BearStiff}} := 4$$

$$t_{\text{BearStiff}} = 4 \quad (\text{mm})$$

$$A_{\text{BearStiff}} := t_{\text{BearStiff}} \cdot b_{\text{fb}} + 12 \cdot t_w^2$$

$$A_{\text{BearStiff}} = 2000 \quad (\text{mm}^2)$$

$$I_{\text{BearStiff}} := \frac{(12 \cdot t_w) \cdot t_w^3}{12} + \frac{t_{\text{BearStiff}} \cdot b_{\text{fb}}^3}{12}$$

$$I_{\text{BearStiff}} = 2676666.67 \quad (\text{mm}^4)$$

$$r_{\text{BearStiff}} := \sqrt{\frac{I_{\text{BearStiff}}}{A_{\text{BearStiff}}}}$$

$$r_{\text{BearStiff}} = 36.583 \quad (\text{mm})$$

$$\lambda_{\text{BearStiff}} := \frac{h_w}{r_{\text{BearStiff}}} \cdot \sqrt{\frac{F_y}{\pi^2 \cdot E}}$$

$$\lambda_{\text{BearStiff}} = 0.150$$

$$F_{\text{BearStiff}} := \begin{cases} (\phi_b \cdot F_y) & \text{if } 0 \leq \lambda_{\text{BearStiff}} \leq 0.15 \\ \left[\phi_b \cdot F_y \cdot (1.035 - 0.202 \cdot \lambda_{\text{BearStiff}} - 0.222 \cdot \lambda_{\text{BearStiff}}^2) \right] & \text{if } 0.15 < \lambda_{\text{BearStiff}} \leq 1 \\ 0 & \text{otherwise} \end{cases}$$

$$F_{\text{BearStiff}} = 269.9 \quad (\text{MPa})$$

$$C_{\text{rBearStiff}} := F_{\text{BearStiff}} \cdot A_{\text{BearStiff}}$$

$$C_{\text{rBearStiff}} = 539792.16 \quad (\text{MPa})$$

$$\text{ResBearStiff} := \begin{cases} \text{"OK"} & \text{if } R_{\text{ShearUltLeft}} \leq C_{\text{rBearStiff}} \\ \text{"FAIL"} & \text{otherwise} \end{cases}$$

$$\text{ResBearStiff} = \text{"OK"}$$

(2) Local Buckling Check:

$$\text{WTR} := 200$$

Width to Thickness Ratio

$$\text{WTR} = 200$$

$$t_{\text{BearStiffMin}} := \frac{b_{\text{fb}} \cdot \sqrt{F_y}}{2 \cdot \text{WTR}}$$

$$t_{\text{BearStiffMin}} = 8.660 \quad (\text{mm})$$

$$t_{\text{BearStiffPrelim}} := \begin{cases} t_{\text{BearStiff}} & \text{if } t_{\text{BearStiff}} \geq t_{\text{BearStiffMin}} \\ t_{\text{BearStiffMin}} & \text{otherwise} \end{cases}$$

$$t_{\text{BearStiffPrelim}} = 8.660 \quad (\text{mm})$$

$$t_{\text{BearStiff}} := \begin{cases} 7 & \text{if } t_{\text{BearStiffPrelim}} \leq 7 \\ 8 & \text{if } 7 < t_{\text{BearStiffPrelim}} \leq 8 \\ 10 & \text{if } 8 < t_{\text{BearStiffPrelim}} \leq 10 \\ 12 & \text{otherwise} \end{cases}$$

$$t_{\text{BearStiff}} = 10 \quad (\text{mm})$$

Welds:**Weld between web and stiffeners:**

Load to be carried =>

$$\phi_{\text{material}} := 0.9$$

$$e := 5$$

$$\phi_{\text{weld}} := 0.67$$

$$f_{y,\text{Mat}} := 300$$

$$f_{y,\text{Weld}} := 410$$

$$V_{r,\text{Mat}} := 0.67 \cdot \phi_{\text{material}} \cdot e \cdot f_{y,\text{Mat}}$$

$$V_{r,\text{Mat}} = 904.5$$

$$V_{r,\text{Weld}} := 0.67 \cdot \phi_{\text{weld}} \cdot \left(\cos\left(\frac{\pi}{4}\right) \right) \cdot e \cdot f_{y,\text{Weld}}$$

$$V_{r,\text{Weld}} = 650.71$$

$$\text{Length}_{\text{req}} := \frac{V_{ui}}{V_{r,\text{Weld}}}$$

$$\text{Length}_{\text{req}} = 153.68$$

Weld between web and flange:

$$Q_{\text{bot}} := b_{\text{ft}} \cdot b_{\text{fb}} \cdot \left(h_{\text{w}} - Y_{\text{NA}} + t_{\text{ft}} + \frac{b_{\text{ft}}}{2} \right)$$

$$V_{\text{weld},\text{bot}} := \frac{V_{ui} \cdot Q_{\text{bot}}}{2 \cdot I_{xx}}$$

$$V_{\text{weld},\text{bot}} = 70.443$$

$$Q_{\text{top}} := t_{\text{ft}} \cdot t_{\text{fb}} \cdot \left(Y_{\text{NA}} - \frac{t_{\text{ft}}}{2} \right)$$

$$V_{\text{weld},\text{top}} := \frac{V_{ui} \cdot Q_{\text{top}}}{2 \cdot I_{xx}}$$

$$V_{\text{weld},\text{top}} = 109.809$$

$$e := 3.15 \cdot \frac{V_{\text{weld},\text{top}}}{f_{y,\text{Weld}}}$$

$$e = 0.844$$

$$e_{\text{min}} := 6 \quad \text{mm}$$

For Plate Thickness of 20mm

Summary of Girder Properties:

$t_{fb} = 300 \quad (\text{mm})$

$t_{ft} = 20 \quad (\text{mm})$

$h_w = 450 \quad (\text{mm})$

$t_w = 10 \quad (\text{mm})$

$b_{fb} = 200 \quad (\text{mm})$

$b_{ft} = 10 \quad (\text{mm})$

$t_{\text{BearStiff}} = 10 \quad (\text{mm})$

$S = 900 \quad (\text{mm})$

$L_{CG} = 4500 \quad (\text{mm})$